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PRACTICAL PLANE GEOMETRY

GIVING

THE SIMPLEST MODES OF CONSTRUCTING FIGURES CONTAINED IN ONE PLANE

AND

GEOMETRICAL CONSTRUCTION ON THE GROUND

BY J. F. HEATHER, M.A.

LATE OF THE ROYAL MILITARY ACADEMY, WOOLWICH, ETC.

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PREFACE.

THE Elements of Euclid form a complete course of the *theoretical* principles of Geometry, and the problems contained in them are designed to establish the possibility of performing the several constructions required for the proofs of those principles, before assuming these constructions in the succeeding propositions. For this purpose, then, the simplest modes of *proof* have been adopted.

But for the purposes of *Practical* Geometry the simplest mode of *performing* the constructions, consistent with the greatest degree of accuracy, is to be looked for. This necessitates variations from the methods of Euclid : and consequently, even for those problems which are contained in the Elements, as well as for the numerous deductions from them in the following pages, proofs of the methods actually employed herein have been given. The theorems, however, upon which they depend have merely been enunciated, and references given to the propositions of Euclid in which they are to be found.

Numerous references throughout the work give the numbers of the theorems, problems, or articles stating the principles upon which the processes depend.

The objects of the work have been to give such a course of Practical Plane Geometry as shall enable candidates perfectly to master the constructions given in papers for competitive examinations on the subject.

A chapter has also been added on Geometrical Construction on the Ground, which it is hoped will be found useful to the engineering student.

NOTE.—The student who desires to pursue the subject of Geometry beyond the limits of the present work can avail himself of the Author's further treatise (also published in this series) on *Descriptive Geometry*, in which will be found included a Theory of Shadows and Perspective, and a description of the principles and practice of Isometrical Projection. The volume serves as an introduction to the application of Descriptive Geometry to various branches of the arts.

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PRACTICAL PLANE GEOMETRY.

CHAPTER I.

DEFINITIONS AND PRELIMINARY NOTIONS.

1. Any common object is termed geometrically, a *solid.*

2. The boundaries of a solid are termed *superficies*, or *surfaces.*

3. The boundaries, or intersections, of surfaces are termed *lines.*

4. The extremities or intersections of lines are termed *points*

Thus A B C D E F G, Fig. 1, represents a *solid;* A B C G, G C D E, and A G E F, represent *surfaces*, and are also called *faces* of the solid; A B, B C, C D, D E, C G, G E, A F, A G, and E F, represent *lines;* A, the extremity of the line A B, or of the line A G, or the intersection of these two lines, represents a point; and in like manner B, C, D, E, F, and G represent points.

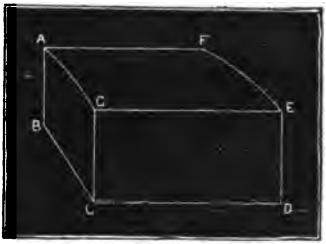

Fig. 1.

5. Surfaces are either *plane*, as A B C G, and G C D E, or *curved*, as A G E F.

6. Lines are either *straight*, or *right*, lines, as A B, B C, C D, &c., or *curved* lines, as A G and E F.

7. The lines that bound the faces of a solid are called the *edges* of the solid, and, when straight, are called *straight edges.*

All the light that, proceeding from one point of an object, passes through the pupil of the eye, is again brought to a point on a fine net-work, called the retina, at the back of the interior of the eye, and thus forms on the retina an image, which conveys to the mind the sensation of vision of that point of the object; and the position of the image on the retina conveys the notion of the direction of the point from the eye. Thus the light from the point A_1, Fig. 2, passing through the pupil, P, is brought again to a point at a_1, on the retina, and is seen in the direction a_1, P, while the point A_2 is in like manner seen in the direction a_2 P.

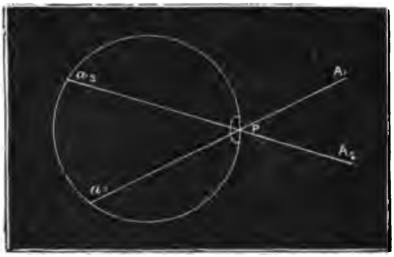

Fig. 2.

Now any line, A B, Fig. 3, may be so looked at that its extreme points, A and B, may lie in the same direction from the eye; so as only to form on the retina the image *a*, of the single point A; and if the line lies evenly between its extreme points A and B, so that at the same time every other point in it lies in the same direction from the eye, as its extreme points, and, consequently, the image in the retina, of the entire line, is but the single point *a*, then A B is termed a straight line; that is, as defined by Euclid.

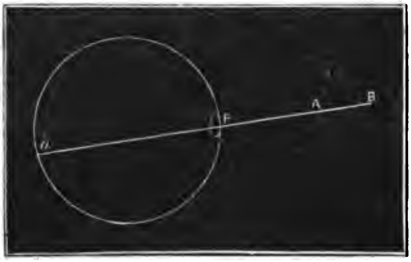

Fig. 3.

8. A *straight* line is that which lies *evenly* between its extreme points.

Hence we understand how a workman can test the straightness of a line by looking along it, and seeing whether in one particular position the whole of it appears but as a single point; while the slightest deviation from this position, in any direction, brings it into view as a continuous line.

9. It follows from the definition that, if the extremities of two *straight* lines coincide, the lines must coincide throughout; so that two *straight* lines cannot inclose a space.

10. If, however, either one, or both, of two lines be *curved*, they can always be made to inclose a space.

From these two axioms it follows that having once procured a *straight edge*, any other edge made to coincide with it will also be *straight*, and any line drawn close along such an edge will also be straight.*

11. A plane or flat surface is that on which any two points being taken, the straight line between them lies wholly in the surface.

Hence to test the flatness of a surface, a straight edge is to be laid upon it, and if it coincide with the surface in every position in which it can be placed upon it, so that no light can be seen between the edge and the surface, the surface is a true plane.

12. Let A B, Fig. 4, be a fixed straight line, and let another straight line A C be first placed in coincidence with A B, and then be moved round the extremity A, continually changing its direction, until it again comes into coincidence with A B: it is then said to have made a complete revolution.

13. When A C, Fig. 4, has moved through a portion of a complete revolution, its inclination to A B is called a *rectilineal angle*, and the magnitude of the angle is measured by the portion of a complete revolution through which it has moved, and is entirely independent of the lengths of the sides A B, A C.

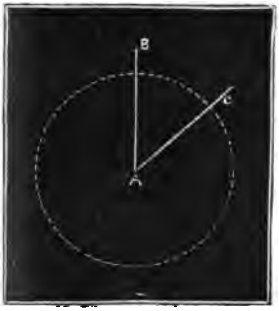

Fig. 4.

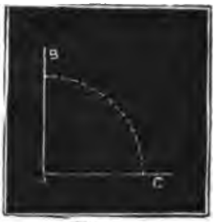

Fig. 5.

14. A complete revolution is divided into four right angles; hence when A C, Fig. 5, has moved through one-fourth of a revolution, the angle B A C is a right angle.

15. If A C, Fig. 6, move through two right angles, or half a complete revolution, it comes into the same straight line with A B, but in an opposite direction.

---

* See *Straight Edge*, in "Mathematical Instruments," by J. F. Heather, Weale's Series.

16. An angle which is either greater, or less, than a right angle, is called an *oblique* angle. If less than a right-angle, as B A C_1, Fig. 7, it is called *acute;* and if greater than a right angle as B A C_2, it is called *obtuse.*

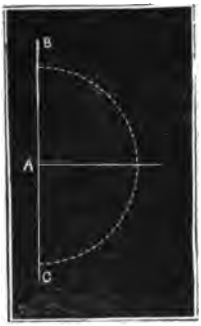

Fig. 6.

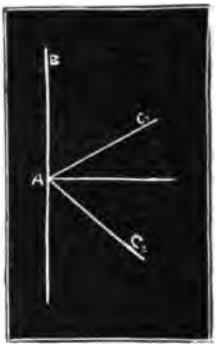

Fig 7

17. It appears then that if B A B′, Fig. 8, is a straight line, and A C be moved round A, from the direction A B, through one-fourth of a complete revolution, the angles B A C, and C A B′, are both right angles, and are equal. In this case, A C is said to be at right-angles to B A B′.

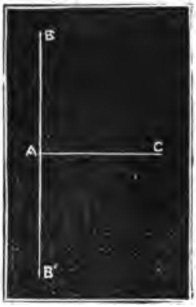

Fig. 8.

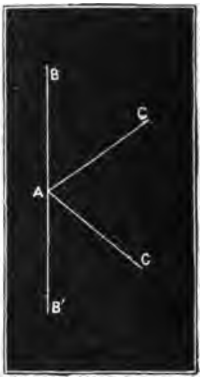

Fig. 9.

18. But if A C, Fig. 9, move through either more or less

than a fourth of a complete revolution, it is said to be oblique to B A B′, and the angles B A C and C A B′ are unequal, one being obtuse and the other acute.

The defect of an angle from a right angle is called its *complement*, and the defect from two right angles its *supplement*.

19. Straight lines in the same plane that will not meet however far they may be produced in either direction, are called *parallels*.

20. The lines that bound a surface, or portion of a surface, are called its *sides;* the surface itself is called a *figure;* and the angles between the sides are called the *angles of the figure*.

21. Figures bounded by straight lines are called *rectilineal*.

22. When the sides and angles of one figure are respectively equal to the sides and angles of another figure, each to each, the figures themselves are equal; but the figures may also be equal, without any equality between their sides and angles.

23. Equal figures of the latter kind may be termed *equivalent* figures, to distinguish them from those which have all their dimensions equal respectively the one to the other.

24. Two figures which have their angles equal each to each, and the sides about the equal angles proportional, are said to be *similar*.

25. A figure contained by three straight lines is called a *triangle*. A triangle has, therefore, three sides and three angles

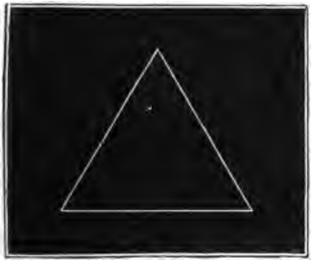

Fig. 10.

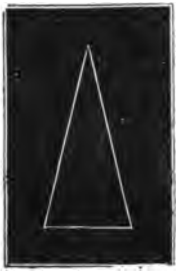

Fig. 11.

26. When the three sides of a triangle are equal to one another, it is called an *equilateral* triangle (Fig. 10).

27. When two of the sides of a triangle are equal to one another, it is called an *isosceles* triangle (Fig. 11).

28. When one of the angles of a triangle is a right angle, it is called a *right-angled* triangle (Fig 12).

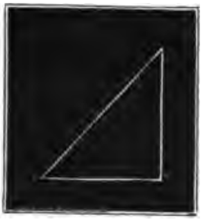

Fig. 12.

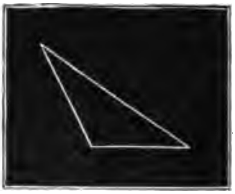

Fig. 13.

The side of a right-angled triangle which is opposite to the right angle, is called the *hypothenuse.*

29. When all the angles of a triangle are oblique, it is called an *oblique-angled* triangle; if one of the angles be obtuse, it is called an *obtuse-angled* triangle (Fig. 13); if not, it is called an *acute-angled* triangle (Fig. 14).

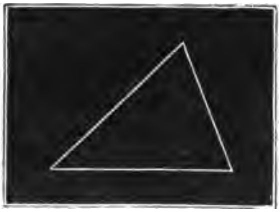

Fig. 14.

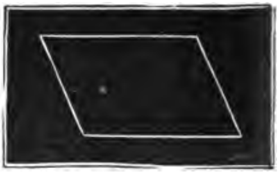

Fig. 15.

30. All four-sided figures are called *quadrilaterals.*

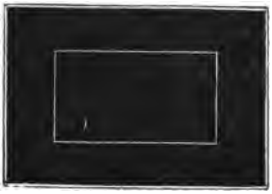

Fig. 16.

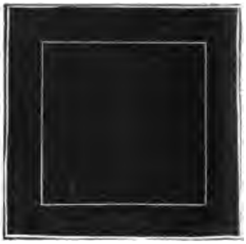

Fig. 17.

31. A quadrilateral having its opposite sides parallel, is called a *parallelogram* (Fig. 15).

32. When one of the angles of a parallelogram is a right angle, all its angles are right angles, and it is called a *rectangle* (Fig. 16.)

33. When the adjacent sides of a rectangle are equal, all the sides are equal, and it is called a *square* (Fig. 17).

34. A parallelogram which is equilateral, but not rectangular, is called a *rhombus* (Fig. 18).

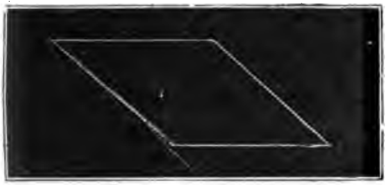

Fig. 18.

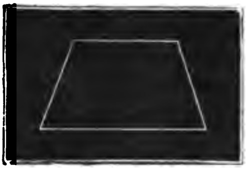

Fig. 19.

35. When *only two* of the sides of a quadrilateral are parallel, it is called a *trapezoid* (Fig. 19).

36. All other four-sided figures are called *trapeziums.*

37. A figure bounded by a single line, which is everywhere at the same distance from a fixed point, is called a *circle* (Fig. 20).

38. The fixed point C, is called the *centre* of the circle.

39. The boundary line A D B E is called the *circumference* of the circle.

40. The fixed distance between the centre and the circumference, that is, any straight line drawn from the centre to the circumference, is called a *radius* of the circle. Thus C A, C D, C B, C E, are *radii* of the circle.

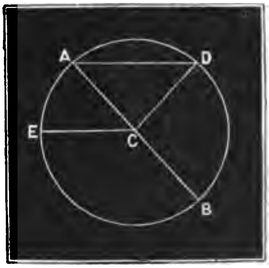

Fig. 20.

41. Any straight line, A B, passing through the centre, and terminated both ways by the circumference, is called a *diameter* of the circle.

42. Any straight line, A D, terminated both ways by the circumference, but not passing through the centre, is called a *chord* of the circle.

43. The figure contained by a diameter and the portion of the circumference it cuts off, is called a *semicircle* (Fig. 21).

44. The figure contained by a chord and the portion of

the circumference it cuts off, is called a *segment* of a circle (Fig. 22).

45. The portion of the circumference cut off by a chord is called an *arc*, and the portion cut off by a diameter, a *semi-circumference.*

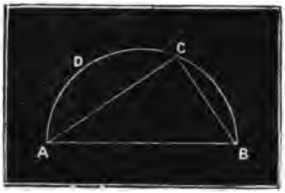

Fig. 21.

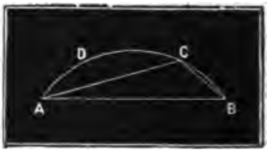

Fig. 22.

46. The chord A B is called the *base of the segment.*

47. The angle D A B, between the base and the arc, is called the *angle* OF *the segment.*

48. The angle A C B, between two lines, C A, C B, drawn from a point on the arc to the extremities of the base, is called the *angle* IN *the segment.*

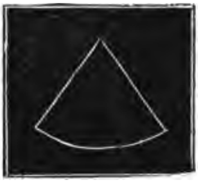

Fig. 23.

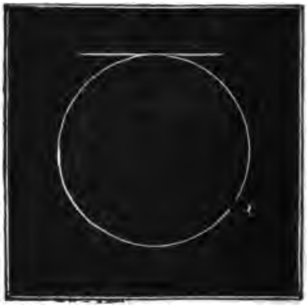

Fig. 24.

49. The figure bounded by two radii, and the arc between them, is called a *sector* (Fig. 23).

50. A straight line is said to *touch* a circle, or is called a *tangent* to it, when it meets the circle, but, though produced, cannot cut it (Fig 24).

51. Two circles are said to touch one another which meet but do not cut one another, (Fig. 25).

52. A rectilineal figure is said to be *inscribed* in another rectilineal figure, when all the angular points of the inscribed figure are upon the sides of the figure in which it is inscribed.

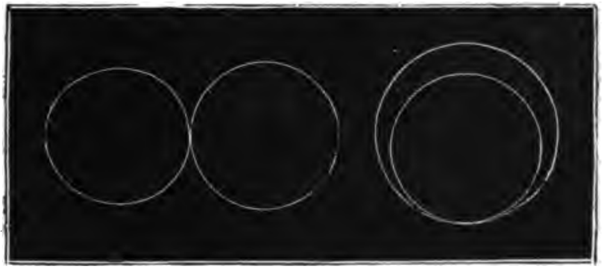

Fig. 25.

53. And conversely, a rectilineal figure is said to be described about another rectilineal figure, when the sides of the described figure pass through the angular points of the figure about which it is described (Fig. 26).

54. When a circle passes through all the angular points of any plane rectilineal figure, the figure is said to be *inscribed in* the circle, and the circle is said to be *described about* the figure (Fig. 27).

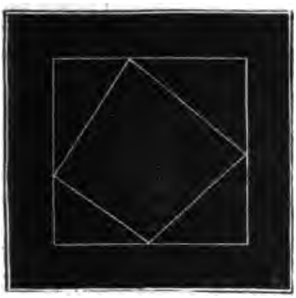

Fig. 26.

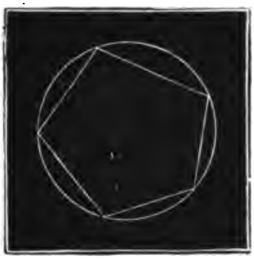

Fig. 27.

55. When a circle touches all the sides of any plane rectilineal figure, the circle is said to be *inscribed in* the figure, and the figure is said to be *described about* the circle (Fig. 28).

56. *Graphic Notation.*—Lines have neither breadth nor thick-

ness, but only length, and they are represented by fine strokes or dots, or a combination of strokes and dots.

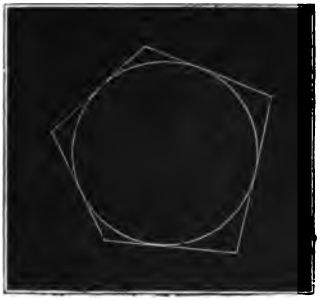

Fig. 28.

Lines belonging to the data, or given conditions of a problem, will be marked by continuous fine lines; thus

————————————

Lines belonging to the quæsita, or solution of a problem, will be marked by thicker lines thus

━━━━━━━━━━━━

Points belonging to the data of a problem will be marked by the intersection of two fine short strokes; thus ×. Points belonging to the quæsita of a problem will be marked by placing small circles round them; thus ⊙. Lines used in the construction of a problem will generally be marked by linked lines formed of a succession of short strokes; thus

— — — — — — — — — — — — —

Lines used in the construction, which it is desirable to distinguish as of more than ordinary importance, will be marked by link-dotted lines formed of a mixture of strokes and dots; thus—

— · — · — · — · — · — · — · —

— · · — · · — · · — · · — · · —

The greater number of interposed dots denoting a greater degree of relative importance. It is, however, generally sufficient to draw those portions only of lines of construction which indicate points to be determined by them.

57. *Instruments.*—The instruments absolutely necessary for geometrical constructions, are *pencil*, *drawing-pen*, and *straight-edge*, for *drawing straight lines;* *compasses*, for *taking off distances*, and *describing arcs*, and *circles;* and a *plane scale*, and *protractor*, for the *measurement* of *lengths* and *angles*. Other instruments are used for the more rapid and convenient construction of particular classes of problems.

58. To draw good lines requires more practice than would at first be supposed for an operation that appears so simple. The student should, therefore, begin with such exercises as the following, but on a much larger scale than here represented.

Exercises.

(1). Draw series of lines, fine, thick, linked, and link-dotted (Fig. 29).

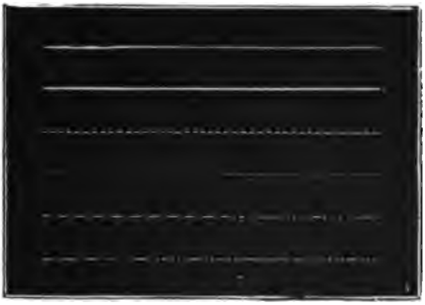

Fig. 29.

(2). Draw series of concentric arcs, fine, thick, linked, and linked-dotted (Fig. 30).

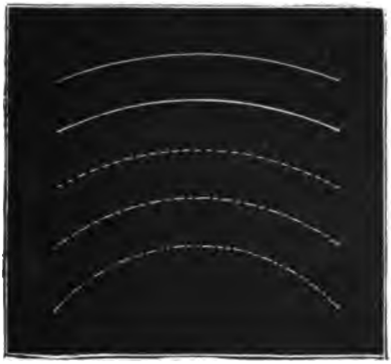

Fig. 30.

(3). Mark against a straight-edge three points, two or three inches apart, removing the straight-edge cover one of the extreme points, replace the straight-edge and draw a very fine straight line through the two uncovered points, producing it as far as possible; and again uncovering the extreme point see if the production of the line just drawn will pass through it.

(4). Take a line, A B, Fig. 31, not less than three inches long, open the points of the compasses to the distance A B, with this distance strike arcs from A and B intersecting in C, from A and C intersecting in D, and from B and C intersecting in E; then the points D, C, and E, should be in a straight line.

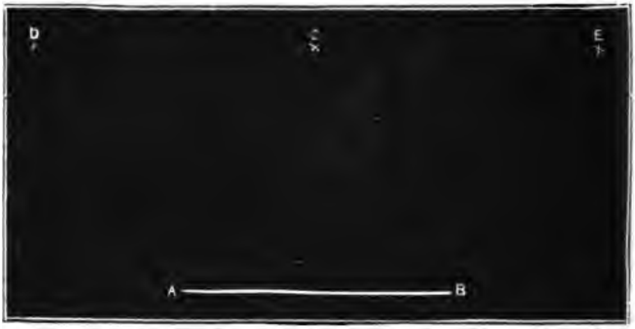

Fig. 31.

Test them with a straight-edge, or first determine the points C and D, and draw a straight line through them; and then finding the third point, E, it should come upon the straight line thus drawn.

CHAPTER II.

ON STRAIGHT LINES, ANGLES, AND RECTILINEAL FIGURES.

Note.—Two triangles will be said to be equal in all respects, when not only the figures themselves are equal, but also their corresponding sides and angles are equal, each to each; or, in other words, when they are exactly alike both in *magnitude* and *form.*

Theorems.

59. Theor. 1. When two sides and the included angle of one triangle are equal to two sides and the included angle of another triangle, each to each, the triangles shall be equal in all respects (Euc. I. 4).

60. Theor. 2. When the three sides of one triangle are equal to the three sides of another triangle, each to each, the triangles shall be equal in all respects (Euc. I. 8).

60*. Theor. 3. When two angles of one triangle are equal to two angles of another triangle, each to each, and a side of one is equal to a side of the other, the triangles are equal in all respects (Euc. I. 26).

61. **Theor.** 4. When two sides of a triangle are equal to one another, the angles opposite to those sides are also equal to one another; and, conversely, when two angles are equal, the sides opposite to them are also equal (Euc. I. 5 and 6). Hence every equilateral triangle is also equiangular, and *vice versâ*.

62. **Theor.** 5. If one side of a triangle be produced, the exterior angle is equal to the two interior and opposite angles; and the three angles of every triangle are together equal to two right angles (Euc. I. 32). Hence the angles of an equilateral triangle are each equal to one-third of two right angles, or to 60°.

63. **Theor.** 6. All the interior angles of any rectilinieal figure together with four right angles, are equal to twice as many right angles as the figure has sides (Euc. I. 32. Cor. 1). Hence the angles of a regular polygon are each equal to the quotient obtained by dividing twice as many right angles as the figure has sides, less four right angles, by the number of sides:—Thus, for a regular pentagon, or five-sided figure, all the five angles are equal to ten right angles less four, or to six right angles; and therefore each of the angles is a fifth part of six right angles, and contains $\frac{6 \times 90^\circ}{5}$, or 108°.

64. **Theor.** 7. When two straight lines intersect one another, the vertical or opposite angles are equal (Euc. I. 15).

65. **Theor.** 8. When a straight line, falling upon two other straight lines, makes the alternate angles equal to one another, these two straight lines shall be parallel to one another (Euc. I. 27).

66. **Theor.** 9. When a straight line, falling upon two other straight lines, makes the exterior angle equal to the interior and opposite angle upon the same side of the line; or makes the interior angles upon the same side together equal to two right angles; the two straight lines shall be parallel to one another (Euc. I. 28).

66*. **Theor.** 10. Straight lines which join the extremities of equal and parallel straight lines are themselves equal and parallel (Euc. I. 33).

67. **Theor.** 11. The opposite sides and angles of a parallelogram are equal, and the diagonal bisects it (Euc. 1. 34).

67*. **Theor.** 12. In any right-angled triangle, the square described upon the hypothenuse, or side opposite to the right angle, is equal to the squares described on the sides which contain the right angle (Euc. I. 47).

68. Theor. 13. If the square described upon one of the sides of a triangle be equal to the squares described upon the other two sides of it, the angle contained by these two sides is a right angle (Euc. I. 48).

69. Theor. 14. The angle in a semicircle is a right angle (Euc. III. 31).

Problems.

70. Problem I.—*To make a triangle equal in all respects to a given triangle, or having its sides of given lengths.*

Draw a straight line, and upon it set off A B, Fig. 32, equal to *a b*, one of the sides of the given triangle, or to one of the given lengths; from A and B as centres strike arcs with radii respectively equal to *a c*, and *b c*, the other sides of the triangle, or to the other given lengths, and let the arcs intersect in C; then drawing the lines A C and B C, A B C will be the required triangle.

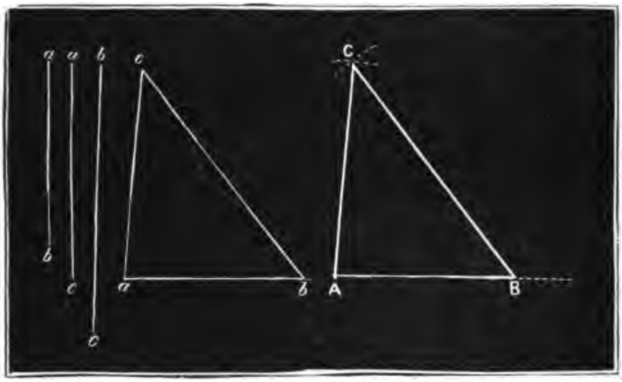

Fig. 32.

Note 1.—When the lengths are given either by lines already drawn, or by stated measurements, any two of these lengths must together be greater than the third; otherwise the arcs described above will not intersect, and no triangle can be formed with such dimensions.

Note 2.—If the three given lengths be equal the triangle will be equilateral, and if two of them only be equal to one another, the triangle will be isosceles.

71. **Problem 2.**—***To bisect a given rectilineal angle, that is, to divide it into two equal angles.***

Open the points of the compasses to any convenient distance, and from the angular point, or vertex, A, Fig. 33, as a centre, strike an arc cutting the sides in the points B and C; with a distance equal to about three-quarters of that from B to C (see *Note* 2 below), strike arcs from B and C, as centres, intersecting in D; then the straight line drawn from A through D will be the bisecting line required.

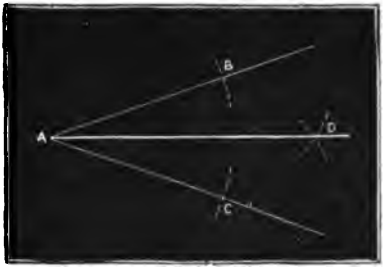

Fig. 33.

Reason.—Suppose the straight lines B D and C D to be drawn, then (Theor. 2) the triangles A B D and A C D will be equal in all respects, and, consequently, the angles B A D and C A D are equal.

Note 1.—The greater the distance between two points determining a line, the more accurately can the line be drawn.

Note 2.—The more nearly at right angles two lines intersect, the more accurately will this point of intersection be marked.

Exercises.

(1.) Construct an isosceles triangle having the equal sides $2\frac{1}{2}$ inches long, and the third side 1 inch, and bisect each of the angles. The three bisecting lines should meet in a point.

(2.) Construct an equilateral triangle, and by bisections, construct angles of 30°, 90°, 15°, 45°, and $22\frac{1}{2}$°.

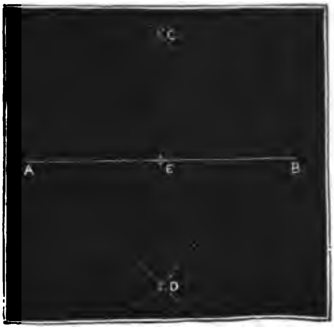

Fig. 34.

72. **Problem 3.**—*To bisect a given straight line.*

Open the points of the compasses to a distance equal to about three-fourths the length of the given line A B, Fig. 34; with this distance strike arcs intersecting at C and D;

lay the straight-edge to pass through the intersections, and mark at E the point in which it crosses the line A B; then A B will be bisected at this point.

Reason.—Suppose the lines C A, C B, and C E to be drawn; then the angle A C B will be bisected by the line C E: hence the triangles C A E and C B E, will be equal in all respects (Theor. 1.); and, consequently, A E is equal E B.

Exercises.

(1.) Construct triangles of various dimensions; bisect their sides, and join the points of bisection with the opposite angular points; then if the constructions are correctly performed, the three lines thus drawn in each triangle will intersect in one point.

(2.) Draw a line 3½ inches long, and divide it into eight equal parts.

(3.) Take a line 2½ inches long, and from it determine lengths of 3¾, 1⅞, and $2\frac{13}{16}$ inches.

73. **Problem 4.**—*To draw a straight line at right angles to another straight line from a given point in it.*

Method I.—From the given point A, as a centre, with any convenient radius, strike arcs cutting the line in the points B and C, Fig. 35; from B and C, with radius equal to about three-fourths of the distance between B and C, strike arcs intersecting in D and E; then the line D E, drawn through the points of intersection, will cut the given line at right angles in the point A, as required.

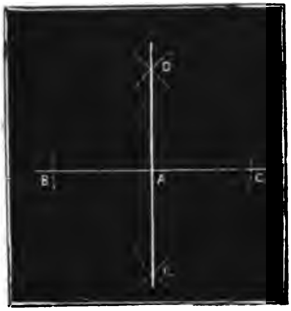

Fig. 35

Reason.—Suppose the lines D B and D C to be drawn; then the triangles D B A, and D C A, will be equal in all respects, as in the preceding problem; consequently the angles D A B, and D A C, will be equal to one another, and will, therefore (17), be right angles.

If the given point be near the end of a line, which cannot conveniently be produced, either of the following methods may be used.

Method II.—Draw a straight line, and set off upon it five equal parts, *a b*, *b c*, *c d*, *d e*, *e f*, Fig. 36; from the given point A, on the given line, as a centre, with radius *a d*, equal to three of the equal parts, strike an arc cutting the line in B; from centres A and B, with radii *a e* and *a f*, equal to four and five of the equal parts respectively, strike arcs intersecting in D; then the straight line drawn through D and A shall be at right angles to A B, as required.

Reason.—$3^2 + 4^2 = 5^2$; hence the square upon B D is equal to the squares upon A B and A D, and, therefore, (Theor. 13), the angle D A B is a right angle.

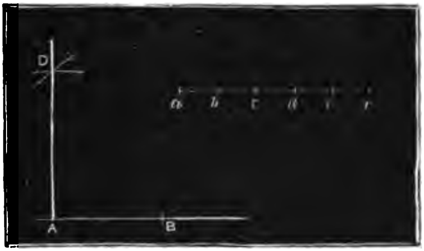

Fig. 36.

Method III.—Open the points of the compasses to any convenient distance and from the given point A. Fig. 37, as a centre, strike a small arc; with the same radius, and any point, E, on this arc as centre, describe a circle B A D cutting the given line in the points A and B; draw a straight line through B and E to meet the circumference of the circle again in the point D; then the straight line drawn through the points D and A shall be at right angles to A B, as required.

Reason.—B E D, being drawn through the centre E, is a diameter of the circle B A D, and, therefore, B A D is an angle in a semicircle, and is a right angle (Theor. 14).

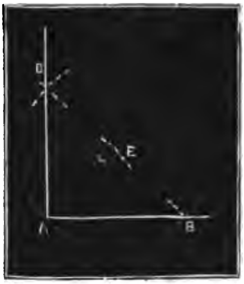

Fig. 37.

It is manifest that the whole circle B A D need not be drawn, but only portions sufficient to determine the points B and D.

Exercises.

(1.) Take any triangle, and erect perpendiculars at the middle points of the sides; then, if correctly constructed, the three perpendiculars should intersect in one point.

(2.) Construct a rectangle, 3½ inches long and 2 inches broad.

(3.) Construct the points of the mariner's compass by drawing two lines at right angles to one another, and dividing the four right angles thus formed, each into eight equal parts.

(4.) A ladder being 20 feet long, construct a figure, and find by measurement how near a wall the foot of the ladder must be placed, that its top may just reach 17 feet up the wall. *Ans.* 10 feet 6½ inches.

74. PROBLEM 5.—*To let fall a perpendicular on a straight line from a given point without it.*

METHOD I.—Open the points of the compasses to a distance somewhat greater than that of the point from the line, and from the given point A, Fig. 38, as centre, strike arcs cutting the line in the points B and C; again from B and C, as centres, with radius equal to about three-fourths of the distance between B and C, strike arcs intersecting in D; the straight line through A and D shall be the perpendicular required.

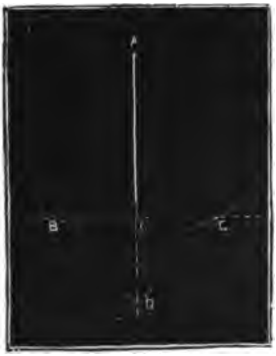

Fig. 38.

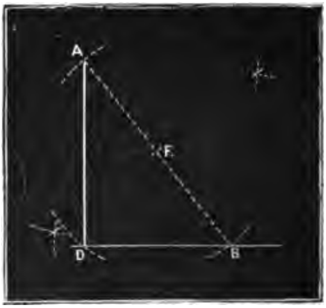

Fig. 39.

Reason.—Identical with that given in Art. 73, Method I.

METHOD II.—When the point is so situated that the perpendicular would fall near the end of the line, and the line cannot conveniently be produced.

From the given point A, Fig. 39, draw the straight line A B, oblique to the given line B D; bisect A B in E; from E, as centre, with radius E A, or E B, strike an arc, cutting the given line in D; then the straight line passing through A and D shall be the perpendicular required.

Reason.—Identical with that in Art. 73, Method III., since

D is a point in the circumference of the semicircle of which A B is the diameter.

EXERCISES.

(1.) Construct any triangle, and let fall perpendiculars on the sides from the opposite angles. If accurately constructed, the three perpendiculars will intersect in one point.

(2.) A person walks 50 yards up a slope inclined at 15° to the horizon; construct a figure, and find by measurement, through what vertical distance he has ascended. *Ans.* 12·94 yds.

The problem of constructing right angles is of such constant occurrence in all Arts and Manufactures, that it becomes of great importance to possess the means of performing it with the greatest facility and precision. In the preparation of plans and designs the desired object is accomplished by the drawing-board and T-square, or by the straight-edge and set-square.*

75. PROBLEM 6.—*To draw lines at right angles, by the straight-edge and set-square.*

The set-square is a thin piece of wood or other material cut into the form of a right-angled triangle.

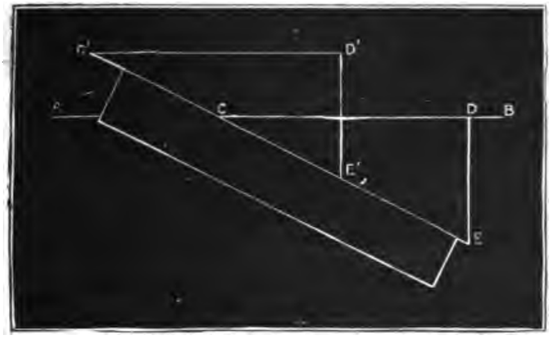

Fig. 40.

Let A B, Fig. 40, be a given line to which it is desired to draw a perpendicular through a given point, either in the line or without it.

METHOD I.—Place one of the sides, C D, of the set-square against the given line; place the straight-edge against the hypothenuse, C E; holding the straight-edge firm, slide the set-square C D E along it into a new position C′ D′ E′, until the side D′ E′ passes through the given point; then a line drawn along D′ E′ will be the perpendicular required.

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* See *T-square* and *Set-square* in "Mathematical Instruments," by J. F. Heather, M.A., Weale's Series.

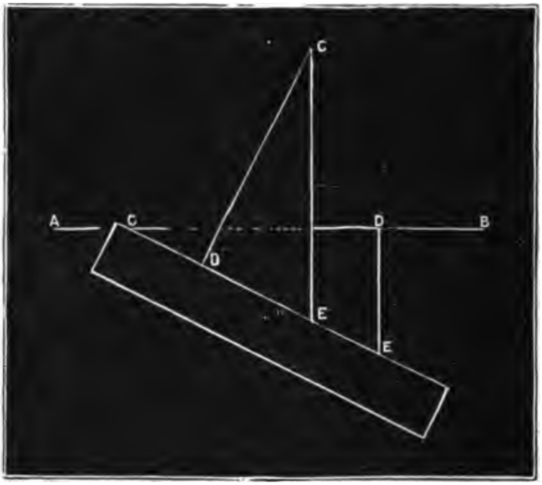

Fig. 41.

Method II.—Place one of the sides C D, Fig. 41, of the set-square against the given line, and the straight-edge against the hypothenuse as before; holding the straight-edge firm, turn the triangle over, and place it in the new position C′ D′ E′, with the other side D′ E′ against the straight-edge, and the hypothenuse C′ E′, passing through the given point; then a line drawn along C′ E′ shall be the perpendicular required.

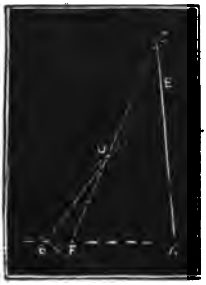

Fig. 42.

76. **Problem 7.**—*To test the accuracy of a supposed right angle B A C.*

From centre A, Fig. 42, strike a small arc; from a point in this arc, and with the same radius, strike arcs intersecting the sides in B and C; then if the points B D C are in one straight line, B A C is a correct right angle; but if not, draw the straight line B D E, through the points B and D, and the straight line C D F, through the points C and D; then the angle B D F, or C D E,* is twice the error, that is twice the angle by which B A C either exceeds or falls short of a right angle.

Suppose B C joined, then if D falls within the triangle C B A, the error is one of defect, and if it falls without the triangle the error is one of excess.

77. PROBLEM 8.—*To test the accuracy of a set-square.*

Place one side D E, Fig. 43, of the set-square in contact with a straight line A B, and draw a line along the other side C D; turn the triangle over into the new position C′ D E′, place the same side D E′ in contact with A B, and draw a line along C′ D; then if the lines C D and C′ D coincide, the set-square is correct; but if not, the angle C D C′ measures twice the error of the supposed right angle C D E.

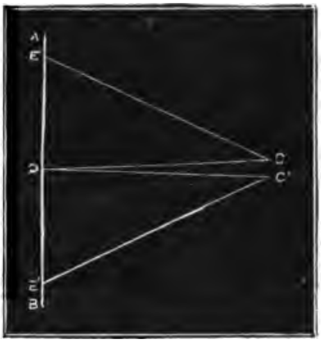

Fig. 43.

78. PROBLEM 9.—*At a given point in a given straight line, to construct an angle equal to a given rectilineal angle.*

METHOD I.—Let A, Fig. 44, be the given angle, B C the given line, and B the given point; from the angular point A, as centre, with any convenient radius, strike arcs cutting the sides of the angle in D, and E; from the centre B, with the same radius, strike an arc C F; take the distance from D to E, as radius,

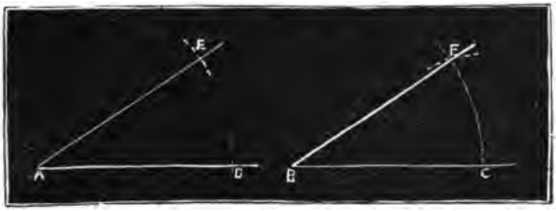

Fig. 44.

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* The angles B D F and C D E are equal (Theor. 6).

and from C, as centre, strike an arc, cutting C F in F; through B and F draw the straight line B F; then shall the angle F B C be equal to the angle at A, as required.

Reason.—Suppose straight lines to be drawn from D to E, and from C to F, then the triangles thus formed will have their sides equal each to each, and will, therefore (Theor. 2), be equal in all respects.

Method II.—Take a piece of paper, and cut one edge, P Q, Fig. 45, straight; place the edge P Q in contact with the side A D of the given angle, and mark upon the paper the points, A and G, where the other side cuts its edges; again, place the piece of paper with its straight edge P Q, in contact with the given line B C, and the point marked in this edge in coincidence with the given point, B; mark at H a point in coincidence with the mark on the other edge of the piece of paper; remove the piece of paper, and draw a straight line through the points B and H; then shall the angle F B C be equal to the given angle at A, as required.

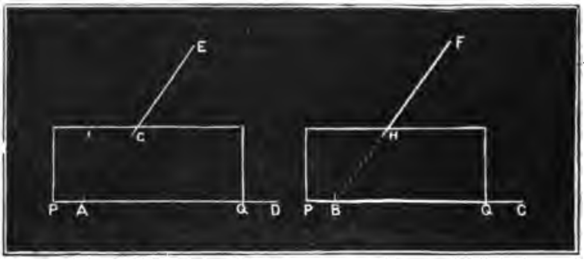

Fig. 45.

Reason.—Identical with that given for the preceding method, the triangle H B Q being an exact copy of the triangle G A Q.

This method indicates the means of constructing protractors, to set off angles, given by their measurements, or to measure angles already laid down.

79. Problem 10.—*To construct a plan of a protractor of the ordinary form, and graduate it at every* 15°.

Construct a rectangle A B C D, Fig. 46, six inches long, and 1½ inches broad; bisect A B at right angles by the straight line P Q, and mark the point where this line cuts the side C D of the rectangle 90°; on P B and P Q describe equilateral triangles P S B and P R Q, and mark the points where P S and P R cut

C D, 60° and 30°, respectively; bisect each of the angles B P R, R P S, and S P Q, and mark the points where the bisecting lines cut the sides B C and C D of the rectangle, 15°, 45°, and 75°, respectively; repeat the construction on the other half of the protractor, and number the graduations from 90° to 180°; then the plan of a protractor will be formed and graduated as desired.*

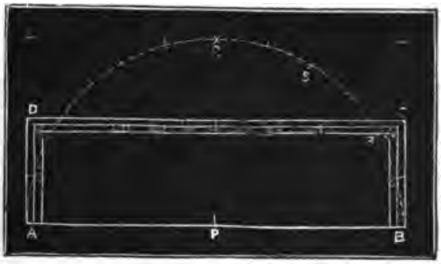

Fig. 46.

80. PROBLEM 11.—*Through a given point to draw a line parallel to a given straight line.*

METHOD I.—Open the points of the compasses to a distance somewhat greater than the distance from the point to the line: from the given point A, Fig. 47, as centre, strike an arc B E, cutting the given line in the point B; from centre B, with the same radius, cut the line again in the point C; take the distance from A to C, and set it off from B to E on the arc B E; then the straight line drawn through E and A shall be the parallel required.

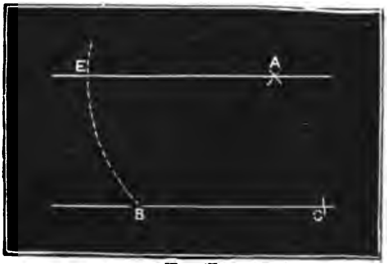

Fig. 47.

Reason.—If A B be joined, the angles E A B and A B C are equal, and they are alternate angles; hence the lines E A and B C are parallel (Theor. 8).

METHOD II.—*By means of the straight-edge and set-square.*—Place one side D E, Fig. 48, of the set-square in contact with the given line B C; place the straight-edge against the hypothenuse D F; holding the straight-edge firm, slide the triangle along it into the new position D′ E′ F′, in which D′ E′ passes through the given point A; then a line drawn along the edge D′ E′ will be the parallel required.*

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* For further information on the construction and use of protractors, see "Mathematical Instruments," Weale's Series.

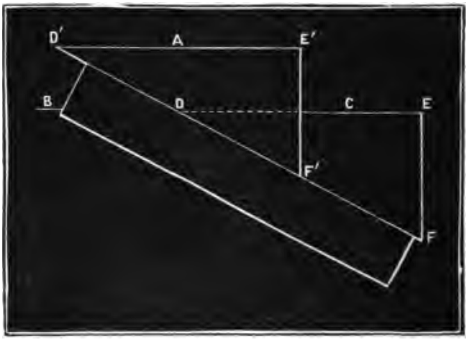

Fig. 48.

Reason.—By this means the exterior angle E D F, is made equal to the interior and opposite angle E′ D′ F′; hence the lines D′ E′ and D E are parallel (Theor. 9).

81. Problem 12.—*To draw a straight line parallel to a given straight line at a given distnce from it.*

Take two points on the given line, the more remote from one another the better; erect perpendiculars at these points; set off the given distance from the points A and B, Fig. 49, to the points C and D on the perpendiculars; then the straight line drawn through C and D will be the parallel required.*

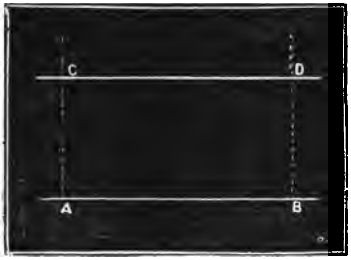

Fig. 49.

Or, erect the perpendicular A C; set off A C equal to the given distance; at C erect C D perpendicular to C A; then C D shall be the parallel required.

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* To draw parallel lines at given distances with the Marquois's scales, see "Mathematical Instruments," Weale's Series.

Reason.—The two interior angles B A C, A C D, are thus made equal to right angles; hence the lines C D and A B are parallel (Theor. 9).

82. Problem 13.—*To bisect the angle by which two straight lines are inclined to one another, when the lines do not meet, and it is not convenient to produce them.*

Parallel to the two given straight lines, Fig. 50, and at equal distances from them, draw two straight lines to meet in the point E; take any convenient distance between the points of the compasses. and with this distance strike an arc from centre E, cutting A B and C D in the points B and D; from centres B and D strike arcs with equal radii intersecting in F; then the line passing through the points E and F shall be the required bisecting line.

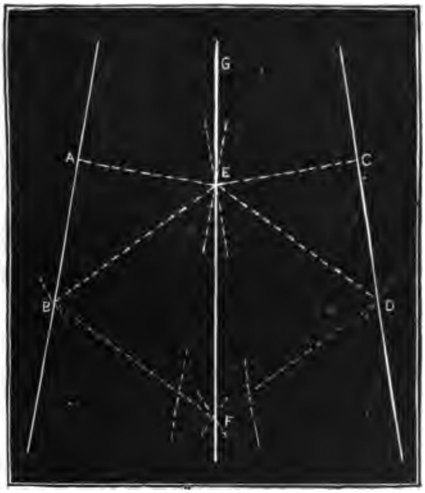


Fig. 50.

Reason.—Draw E A and E C perpendicular to A B and C D respectively; then E A and E C are equal by construction, and also E B and E D; therefore the squares on E A, A B, are equal to the squares on E C, C D (Theor. 12); and, therefore, since E A is equal to E C, A B is also equal to C D, and the triangles E A B, E C D are equal in all respects. In like manner if B A and D C could be produced to meet, and the line E G were drawn from E to the point of meeting, the two triangles thus formed would be equal in all respects, and the angle formed by the two given lines would, therefore, be bisected by the line E G. Also the angle B E A being equal to the angle D E C, and the angle G E A to the angle G E C, the whole angle G E B is equal to the whole angle G E D; but, by the construction the two sides, F E, E B, of the triangle F E B were made equal to the two sides F E, E D, of the triangle F E D, and the base F B to the base F D; therefore the angle F E B is equal to the angle F E D (Theor. 2). Hence the two angles F E B and G E B are equal to the two angles F E D and G E D; but the four angles are together equal to four right angles (14); therefore F E B and G E B are together equal to two right angles, and therefore (15) G E and E F are in the same straight line, and therefore G E F is the required bisecting line.

EXERCISE.

Draw two parallel lines, each 3 inches long, at a distance apart of 3 inches; at one extremity of one of the parallels erect a perpendicular ½ inch in length, draw a line to pass through the other extremity of the line and the end of the perpendicular, and draw a line bisecting the angle between the line last drawn and the other parallel.

83. PROBLEM 14.—*Through a given point between two straight lines not parallel, to draw a third straight line which shall be bisected in that point.*

Through the given point A, Fig. 51, draw the straight line A E, parallel to B D, one of the given straight lines, and meeting the other given line, B C, in the point E; make E C equal to E B; join C A and produce it to meet the line B D in the point D, then C D is the required line bisected in the given point A.

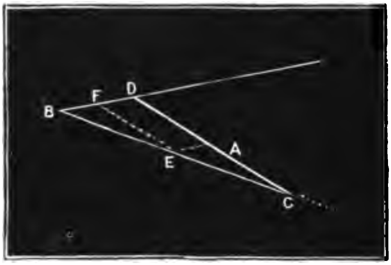


Fig. 51.

Reason.—Through E draw E F parallel to C D, then in the triangles B E F, E C A, the side B E is equal to the side E C, and the angles F B E, B E F, are respectively equal to the angles A E C, E C A; therefore (Theor. 3) F E is equal A C; but F E is equal to A D (Theor. 11); therefore A C is equal to A D, and C D is bisected in A.

EXERCISE.

The lengths of the three sides of a triangle are 1¼ inches, 1½ inches, and 2 inches; take a point on the last side, ½ inch from one of its extremities, and through it draw a line to be terminated by the other sides, or these sides produced, and bisected in the point taken.

84. PROBLEM 15.—*From two given points to draw two straight lines, to meet upon a line given in position, and make equal angles with this line.*

From one of the given points A, Fig. 52, draw A C perpendicular to the line C D given in position; produce A C to E,

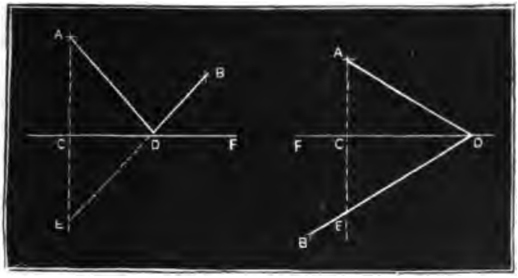


Fig. 52.

making C E equal C A; draw E B joining E with B, the other given point, and meeting the line C D in the point D; join A D, then A D and B D shall be the lines required.

Reason.—Since A C, C D, are equal to E C, C D, and the angle A C D to the angle E C D, therefore (Theor. 1) the triangles A C D, E C D, are equal in all respects, and the angle A D C is equal to the angle E D C; but the angle B D F is either identical with, or vertically opposite to E D C, and therefore equal to it. Hence the angles A D C and B D F are in both cases equal to one another.

Should B E be parallel to C D, no two lines can be drawn to meet on the given line and make equal angles with it.

EXERCISE.

The sides of a triangle have lengths of 1·7 inches, ·9 inches, and 2 inches respectively; from the middle points of two of the sides, draw straight lines to meet in a point upon the third side and make equal angles with it.

85. PROBLEM 16.—*To find a point on a line given in position which shall be equally distant from two given points.*

Draw the line A B, Fig. 53, joining the two given points A and B; bisect A B at right angles by the straight line C D, intersecting the given line in the point D; then D shall be the required point.

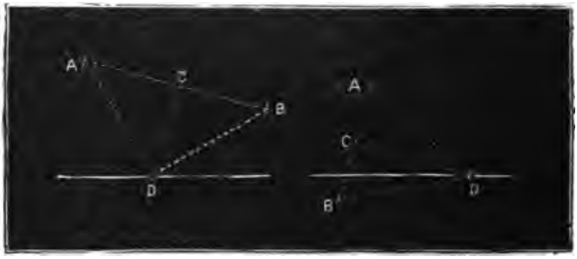


Fig. 53.

Reason.—The triangles A C D, B C D, have the sides A C, C D, respectively equal to the sides B C, C D, and the angle A C D equal to the angle B C D; therefore (Theor. 1) A D is equal to C D.

If A B be perpendicular to the given line, C D will be parallel to it, and there will be no point on the line equidistant from the given points.

EXERCISE.

The base of an isosceles triangle is 1 inch long and each of the sides 2 inches; find a point in the base produced equally distant from the vertex and the middle point of one of the sides.

86. PROBLEM 17.—*To construct a triangle having given two sides and the included angle.*

Draw a straight line and set off on it A B, Fig. 54, equal in length to *a b*, one of the given sides, construct the angle B A C, equal to the given angle *b a c* (Prob. 9); set off on A C the distance A C equal to *a c*, the other given side, and join B C, then A B C will be the required triangle.

Exercises.

(1.) Make a triangle having two of its sides 2 inches and 2¾ inches long, respectively, and the angle between them 45°; determine by measurement the length of the third side. *Ans.* 1·94 inches.

(2.) Two ships sail from the same spot at the same time, one going due north at the rate of 8 miles an hour, and the other south-east at the rate of 10 miles an hour; find how far they will be apart at the end of 2 hours. *Ans.* 33¼ miles.

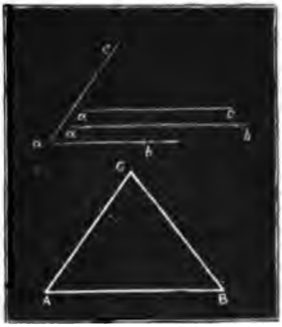


Fig. 54.

87. Problem 18.—*To construct a triangle, having given one side, and the two angles adjacent to this side.*

Draw a straight line and set off on it A B, Fig. 55, equal to

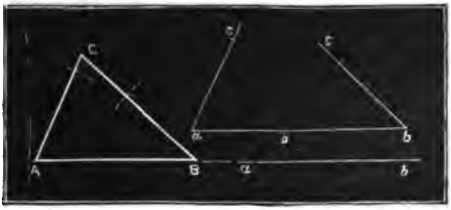


Fig. 55.

the given side, *a b*; construct the angles B A C, and A B C, equal to the given angles *b a c*, and *a b c* (Prob. 9); then A B C is the triangle required.

Exercises.

(1.) The base of a triangle is 50 feet, and the angles at the base are 60° and 45°; construct a figure and find by measurement the perpendicular distance of the vertex from the base. —*Ans.* 31·7 ft.

(2.) The base of an iosceles triangle being 7 inches, and each of the angles at the base 30°, find the length of each of the sides.—*Ans.* 4·04 inches.

Note.—Since the three angles of a triangle are equal to two right angles, when any two angles of a triangle are given the third angle also is given, and hence this problem includes every case in which one side of a triangle and two of its angles are given.

(3.) A man walks 3 miles, turns through an angle of 60° and walks on further, and, after a time, turns again through an angle of 150°, and walks back to the point from which he started; how far did he walk altogether?—*Ans.* 11⅕ miles.

88. PROBLEM 19.—*To construct a triangle, having given two sides and the angle opposite to one of these sides.*

Construct the angle A B C, Fig. 56, equal to the given angle *a b c*; make B A equal to *b a*, the given side adjacent to the given angle; from centre A, with radius equal to *a c*, the side opposite the given angle, describe an arc cutting B C in the point C: then A B C will be the required triangle.

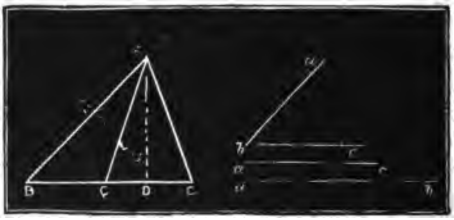


Fig. 56.

Draw A D perpendicular on B C; then it is manifest that if the side opposite the given angle be less than A D, no triangle can be described to answer the required conditions. If this side be equal to A D, the triangle will be right angled. If this side be greater than A D, but less than A B, there will be two triangles answering the required conditions; the two positions of the angular point C being equally distant from the foot D of the perpendicular.

Lastly.—If the side opposite the given angle be greater than the other given side, there will be only one solution (Fig. 57).

Exercises.

(1.) The hypothenuse of a right-angled triangle measures 4 inches, and one of the sides 2½ inches. Construct the triangle.

(2.) One angle of a triangle is 30°, one of the sides containing it is 2½ inches, and the side opposite to it is 1¼ inches. Construct the triangle.

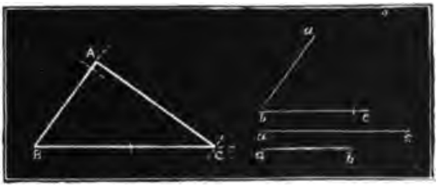


Fig. 57.

(3.) One angle of a triangle is 45°, one of the sides containing this angle is 2 inches, and the side opposite to it is 1½ inches. Construct the triangle.

89. Problem 20.—*To construct a triangle, having given one angle, a side adjacent to it, and the sum of the other two sides.*

Construct the angle D A B, Fig. 58, equal to the given angle

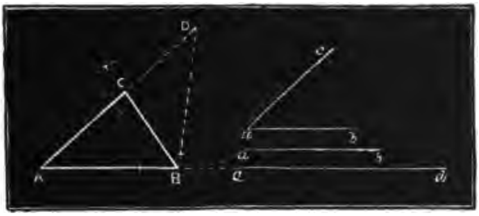


Fig. 58.

c a b; make A B equal to the given side, *a b*, and A D equal to *a d*, the given sum of the other two, and join D B; draw B C, making the angle D B C equal to the triangle B D A, and intersecting A D in C; then A B C shall be the required triangle.

Reason.—The angle C B D being made equal to C D B, the side C B is equal to C D (Theor. 4); therefore A C, C B, together, are equal to A D, the given sum.

EXERCISES.

(1.) The base of a triangle measures 2 inches, the other two sides together 2½ inches, and one of the angles at the base is 40°. Construct the triangle.

(2.) To get to a spot 4 miles due east from him, a man walked for some distance north-east, and then made straight for his destination, walking altogether 5 miles; how far did he walk before changing his direction?—*Ans.* 2·07 miles.

90. PROBLEM 21.—*To construct a triangle, having given one angle, a side adjacent to it, and the difference of the other two sides.*

Construct the angle D A B, Fig. 59, equal to the given angle *d a b*; make A B equal to *a b*, the given side, A D equal to *a d*, the given difference of the other two sides, and join B D; produce A D, and draw B C, making the angle D B C equal to the angle B D C, and meeting B D produced in C; then A B C shall be the required triangle.

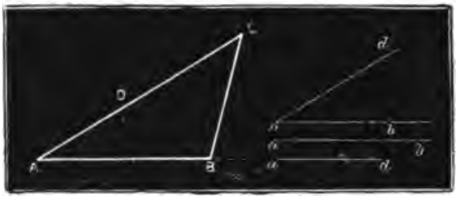


Fig. 59.

Reason.—The angle D B C having been made equal to the angle B D C, the side C B is equal to C D (Theor. 4); therefore the excess of A C above C B is A D, the given difference.

EXERCISE.

One side of a right-angled triangle measures 4 inches, and the difference between the hypothenuse and the other side 1 inch. Construct the triangle.

91. PROBLEM 22.—*To construct a triangle, having given one angle, the side opposite to this angle, and the sum of the two sides containing it.*

Construct the angle B D C, Fig. 60, equal to half the given angle *b a c*; make D B equal to *d b*, the given sum of the two sides; from centre B, with distance equal to *b c*, the given side, intersect D C in the point C; from C draw C A, making the angle D C A equal to the angle C D B, and meeting B D in A; then A B C shall be the required triangle.

Reason.—Since the angles A C D and A D C are equal, the angle B A C, which is equal to these two angles (Theor. 5), is double of one of them, and is therefore equal to the given angle. Also D A is equal to A C, and therefore B A, A C together are equal to B D, the given sum; and B C was made equal to the given side.

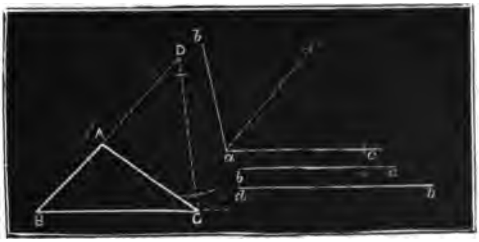


Fig. 60.

EXERCISE.

One angle of a triangle is 50°, the two sides containing it measure together 2½ inches, and the side opposite to it 1½ inches; construct the triangle.

92. PROBLEM 23.—*To construct a triangle, having given one angle, the side opposite that angle, and the difference of the two sides containing it.*

Make B D, Fig. 61, equal to *b d* the given difference, and draw D E at right angles to B D; make the angle E D C equal to half the given angle *b a c*; from centre B, with distance equal to *b c*, the given side, intersect D C in C; produce B D, and draw C A, making the angle D C A equal to the angle C D A and cutting B D produced in A; then A B C shall be the required triangle.

Reason.—Draw A F perpendicular to D C; then because the angle B D C is equal to the two angles D A F and A F D, and that B D E is equal to A F D, each of them being a rigth angle; therefore E D C is equal to D A F; and, therefore, D A F is half the given angle. Again, because the angle A D F is equal to the angle A C F, the right angle A F D to the right angle A F C, and the side A F, common to the two triangles A F D, A F C, these two triangles are equal in all respects, and, therefore, the angle D A F to the angle F A C;

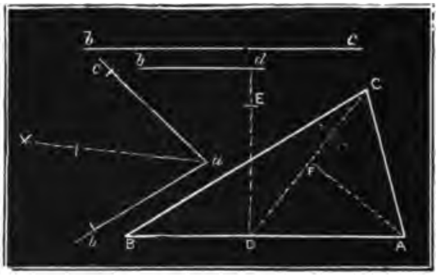


Fig. 61.

therefore the whole angle B A C is double of B A F, and, therefore, equal to the given angle. Also, the side A C is equal to A D, and therefore the excess of A B above A C is equal to B D, the given difference.

Exercise.

One angle of a triangle is 30°, the difference of the sides containing this angle measures half an inch, and the side opposite to it measures two inches.

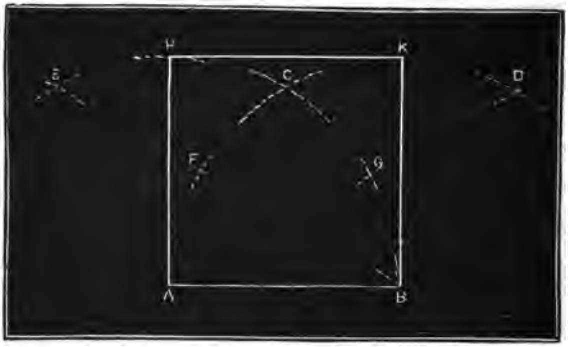


Fig. 62.

93. Problem 24.—*To construct a square upon a given straight line.*

Method I.—Take the length of the given line A B, Fig. 62, between the points of the compasses; and from centres B and A, describe arcs, A C D and B C E, intersecting in C; from C as centre, with the same radius, strike arcs intersecting the arcs A C D, and B C E, in the points D and E; mark the points F and G, in which the straight lines B E and A D cut the ares A C and B C; from centre C, with radius C F or C G, cut the arcs C D and C E in the points K and H; join A H, H K, and K B; then A H K B is the square required.

Reason.—C, A, and B being the angular points of an equilateral triangle, the angles C A B and C B A are each two-thirds of a right angle; and these angles being bisected by the lines A D and B E, and the angles C A H and C B K made equal to the bisections, and consequently each equal to one-third of a right angle, the entire angles H A B and A B K are therefore right angles. Hence A H and B K are parallel, as well as equal; and, therefore, H K and A B are also parallel, and the figure H A B K is a parallelogram. But it also has its adjacent sides at right angles and equal to one another; and therefore is a square.

The equality of the four arcs A F, F C, C G, G B, is a test of the accuracy of the construction.

METHOD II,—Strike the arcs A C K and B C H, Fig. 63, as in the first method; from centre C, with the same radius, strike arcs at D and E; mark the points D and E in which the straight lines A C and B C cut these arcs; draw the straight lines A E and B D, cutting the arcs A C and B C in the points H and K, and join K H; then A B K H is the square required.

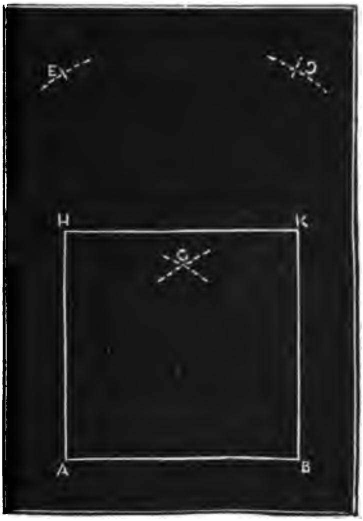


Fig. 63.

Reason.—The points D and E are the extremities of semicircles passing through A and B; hence the angles at A and B are right angles, and H A B K is a square.

94. **Problem 25.**—*To produce a straight line until the rectangle contained by the whole line produced, and the part of it produced, is equal to the square upon the original line.*

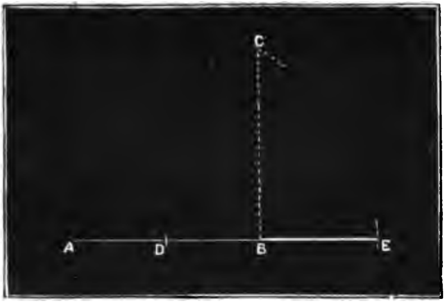


Fig. 64.

From the extremity B of the line A B, Fig. 64, draw B C at right angles to AB, and equal to it; bisect A B in D; from centre D, with radius D C, describe an arc, and produce A B to meet this arc in the point E; then the rectangle A E, E B, shall be equal to the square on A B.

Reason.—

$$A E, E B + D B^2 = D E^2 \text{ (Eu. II., 6)};$$
$$\text{and } D E^2 = D C^2 = D B^2 + B C^2 \text{ (Theor. 12)};$$
$$\text{therefore } A E, E B = B C^2 = A B^2.$$

(*See* also Eu. II., 11.)

95. **Problem 26.**—*On a given base to construct an isosceles triangle, having each of the angles at the base double of the third angle.*

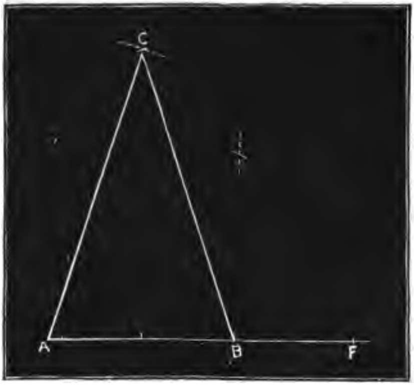


Fig. 65.

By the preceding problem, produce the given line A B to E, Fig. 65, so that the rectangle A E, E B, shall be equal to the square on A B; then A E is the length of each of the equal sides of the required triangle (Eu. IV., 10).

96. Problem 27.—*On a given base to construct an equilateral and equiangular pentagon, or figure of five sides.*

Construct on the given base, A B, Fig. 66, an isosceles triangle, A B C, having each of the angles at the base double of the third angle; with radius A B strike from centres B and C arcs intersecting in D, and from A and C arcs intersecting in E; then A B D C E shall be an equilateral and equiangular pentagon.

For proof *see* Eu. IV., 11.

A check on the accuracy of the work is given by the condition that the five diagonals A D, B C, D E, C A, E B, are all equal to each other.

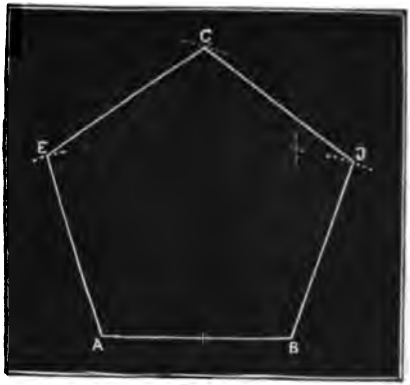


Fig. 66.

97. Problem 28.—*On a given base to construct an equilateral and equiangular hexagon, or figure of six sides.*

On the given base A B, Fig. 67, describe an equilateral triangle A B C; from centre C, with radius C A or C B, describe a circle; produce A C and B C to meet the circle again in the points D and E; set off the distance A B from B or D to F, and from A or E to G; then A B F D E G will be the hexagon required.

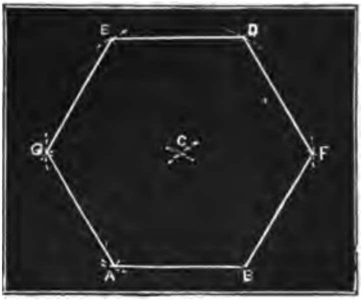


Fig. 67.

For proof *see* Eu. IV., 15.

The points G, C, and F will be in a straight line.

98. Problem 29.—*On a given base to construct an equilateral and equiangular octagon, or figure of eight sides.*

From the extremity B, of the base A B, Fig. 68, draw B C at right angles to A B; set off B C equal to A B, and C D equal to C A; complete the rectangle A B D E, and draw its diagonals intersecting in F; with centre F describe a circle about the rectangle; from the angular points of the rectangle set off the distance A B to the points G H K, and L, on the circumference; and, joining the adjacent points, the required octagon will be described.

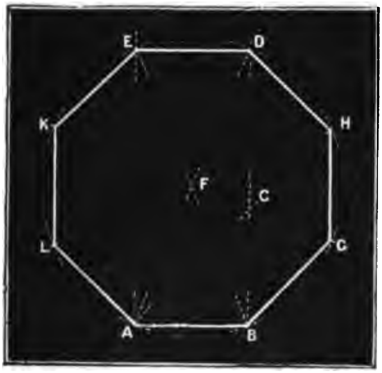


Fig. 68.

Reason.—Since A C is equal to C D, the angles C A D and C D A are equal (Theor. 4), and the angle A C B is therefore double the angle C D A (Theor. 5). In like manner the angle A F B is also double the angle C D A, and therefore equal to the angle A C B.

Again, A B C being a right angle, B A C and A C B are together equal to a right angle (Theor. 5); and they are also equal to one another; therefore, each of them is half a right angle; and hence the angle A F B is also half a right angle. But the triangles B F G and D F H are each made equal in all respects to the triangle A F B; therefore the angles B F G, and D F H, are also each half a right angle, and therefore the remaining angle H F G is also half a right angle. In like manner the other four angles at F are each half a right angle; hence the eight triangles, having their vertices at F, have their vertical angles, and the sides containing these angles, respectively, equal to each other, and are therefore equal in all respects, and consequently the sides of the octagon are all equal to each other, and so also are its angles.

To check the accuracy of the construction, see that L G and K H are each equal to A E or B D.

99. PROBLEM 30.—*On a given base to construct an equilateral and equiangular polygon, or many-sided figure, whatever be the number of sides.*

Divide 360° by twice the number of sides; subtract the quotient from 90°, and the remainder will be the measure of each of the angles between the sides of the figure and the radii of the circumscribing circle. Hence setting off this measurement from either end of the base, the lines thus drawn will intersect at the centre of the circumscribing circle.

For example, let it be required to describe a regular heptagon, or seven-sided figure, on a base two-thirds of an inch in length.

$$\frac{360^\circ}{14} = 25\tfrac{5}{7}^\circ. \text{ and } 90^\circ - 25\tfrac{5}{7} = 64\tfrac{2}{7}.$$

Set off, therefore, at A and B, the angles B A C, and A B C, each equal to $64\frac{2}{7}$; then C, the intersection of A C and B C, is the centre of the circle circumscribing the required heptagon; with centre C and radius C A or C B, describe a circle, step round it with the distance A B, and the required heptagon will be described.

Reason.— Each of the angles C A B and A B C being $64\frac{2}{7}^\circ$, the angle A C B is $180-128\frac{4}{7}$, or $51\frac{3}{7}$ which is equal to $\frac{360^\circ}{7}$; hence there are seven such angles contained in a complete revolution.

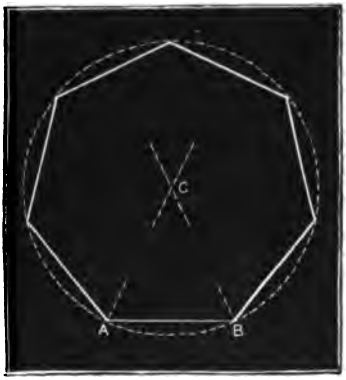


Fig. 69.

From the difficulty of setting off the angle $64\frac{2}{7}$ with sufficient exactness, the points of the compasses, most probably, will not at first come round to the points from which they started, and the position of C will have to be slightly altered; but after two or three trials the object will be accomplished.

100. PROBLEM 31.—*To construct a trapezoid of given dimensions.*

Let A B C D, Fig. 70, be any trapezoid; draw B E parallel to D C; then the problem is reduced to the construction of the triangle A B E, and the completion of the parallelogram E B C D.

Let the lengths of the parallel sides be 5 feet and 2 feet, and the lengths of the slopes 4 feet and 3 feet.

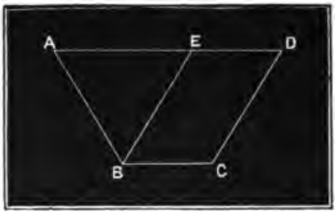


Fig. 70.

Draw the straight line A D, Fig, 71, 5 feet long: set off 2 feet from D to E; from centres A and E, with radii of 4 feet

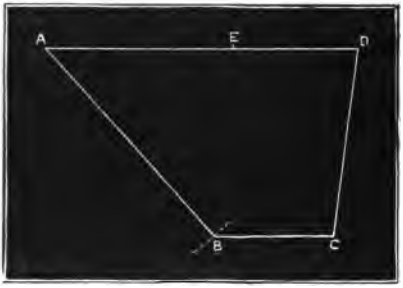


Fig. 71.

and 3 feet, respectively, strike arcs intersecting in B; join A B, B E, and complete the parallelogram E B C D.

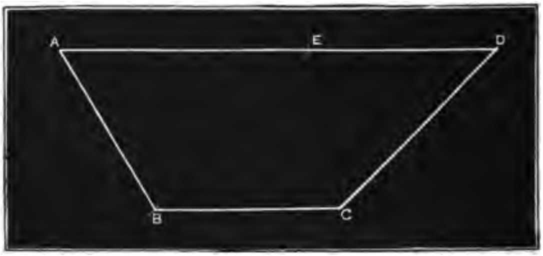


Fig. 72.

Let the lengths of the parallel sides be 7 feet and 3 feet, and the inclinations of the slopes be 60° and 45°.

Draw A D, Fig. 72, 7 feet long, and set off D E equal to 3 feet; make the angles E A B, and A E B, equal to 60° and 45°, respectively, and complete the parallelogram E B C D.

Let the width of a ditch be 8 feet, its depth 3½ feet, and the inclination of the slopes 42° and 54°.

Draw A D, Fig. 73, and F B at right angles to one another; set off F B equal to 3½ feet; make the angles F B A, and F B E equal to 36° and 48°, the complements of 54° and 42°, respectively; set off A D equal to 8 feet, and complete the parallelogram E B C D.

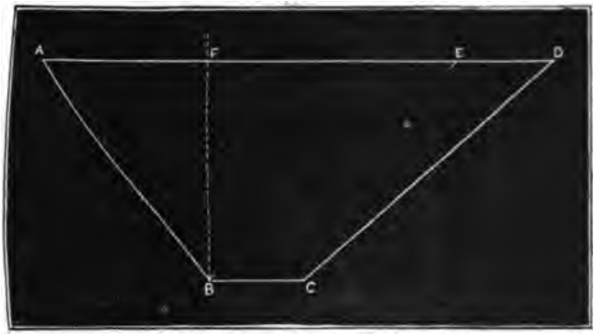


Fig. 73.

101. Every rectilineal figure can be divided into triangles, and in order to construct it sufficient data must be given for the construction of each of these triangles.

102. Exercises on Chapter II.

(1.) A man walks due east 3 miles, and then south 2 miles. Construct a figure and find how far he is from home.—*Ans.* 3·6 miles.

(2.) Construct a square on a line 5 inches long; take a point on one of its diagonals at 3 inches distance from one of the angles through which it is drawn, and find the distances of this point from each of the other angles of the square.—*Ans.* 4·07, 3·58, and 3·58 inches.

(3.) Draw a straight line A B, whose length is limited by two straight lines drawn through a point P, 2·2 inches above the line, the angles B A P, A B P. being 54° and 30° respectively.

(4.) The perimeter of a triangle measures 10 inches, and two of its angles are 35° and 55° respectively. Construct it and measure the length of the sides. *Ans.*—2·4, 3·42, and 4·18 inches.

(5.) The sides of an equiangular hexagon are alternately 2 inches and 1 inch. Construct the figure and measure the lengths of its diagonals. *Ans.*—2·65 inches and 3 inches.

(6.) In a quadrilateral field, A B C D, the distance A D is 120 yards; B E and C F are perpendiculars upon A D; A E and D F are each 40 yards; B E measures 30 yards, and C F 60 yards. Construct a plan of the field, and give the measurements of the other sides and of the diagonals. *Ans.*—A B=50 yards, B C=50 yards, C D=72·11 yards, A C=100 yards, B D=85·44 yards.

(7.) Describe a square upon a line 3 inches long; describe a triangle on the diagonal of the square as base, having its vertex on the middle point of one of the sides of the square; and measure the sides and angles of the triangle.—

Ans.—Sides, $1\frac{1}{2}$ inches, $3\frac{7}{20}$ inches, $4\frac{1}{4}$ inches.
Angles, 18° 26′, 45°, 116° 34′.

(8.) Find the height of a tower whose angle of elevation 200 yards off is 15°.—*Ans.* $53\frac{3}{5}$ yards.

(9.) A man finds that the angle of elevation of the top of a tower is 60°, he recedes from the tower 30 yards, and finds the angle reduced to 30°; find the height of the tower.—*Ans.* 26 yards.

(10.) A tower stands on a cliff; from a boat 100 yards from the base of the cliff, the elevation of the foot of the tower is 15°, the boat being moved 100 yards further off, the elevation of the top of the tower is 15°. Find the heights of the cliff and the tower.—*Ans.* Each $26\frac{4}{5}$ yards.

CHAPTER III.

ON THE DIVISION OF LINES AND THE CONSTRUCTION OF SCALES.

THEOREMS.

103. THEOR. 15.—If a straight line be drawn parallel to one of the sides of a triangle it shall cut the other sides, or these produced, proportionally. (Eu. VI. 2.)

104. THEOR. 16.—In a right-angled triangle, if a perpen-

dicular be drawn from the right angle to the base, the perpendicular is a mean proportional between the segments of the base; and each of the sides is a mean proportional between the base, and the segment of it adjacent to that side. (Eu. VI. 8. Cor.)

105. THEOR. 17.—If any number of straight lines be drawn parallel to one of the sides of a triangle, they shall cut the other sides, or these produced, similarly. (Eu. VI. 10).

105.* THEOR. 18.—The sides about the equal angles of equiangular triangles are proportionals; and those which are opposite to equal angles are homologous sides; that is, are antecedents or consequents of the ratios. (Eu. VI. 4.)

PROBLEMS.

106. PROBLEM 32.—*To find a third proportional to two given straight lines.*

METHOD I.—Let the lengths A B, A C, Fig. 74, of the two lines be set off from the angular point upon the two sides of any angle B A C; set off A C again from A to D on A B, or A B produced; mark the point E, in which a parallel through D to the line joining B and C cuts A C; then A E will be the third proportional required.

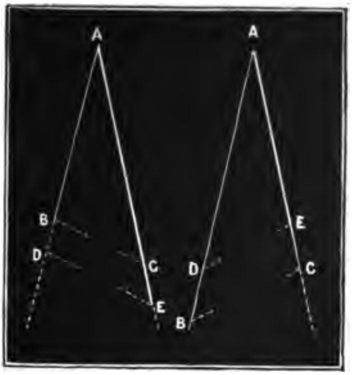


Fig. 74.

Reason.—A B is to A D as A C to A E (Theor. 15); but A D is equal to A C, therefore A B is to A C as A C to A E.

METHOD II.—Construct a right angle B A C, Fig. 75, and let the lengths of the two lines be set off from A to B and

C; join B C, and draw C D at right angles to it, to meet B A produced in D; then will A D be the third proportional required.

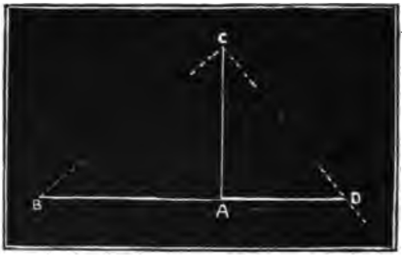


Fig. 75.

Reason.—By Theor. 16, A C is a mean proportional between B A and A D, or A D is a third proportional to B A and A C.

METHOD III.—Construct a right-angled triangle having the shorter of the two given lines, A B, A C, Fig. 76, for one of its sides, and the longer for its hypothenuse; from C draw C D at right angles to this hypothenuse, cutting A B, or A B produced, in D; then shall A D be the third proportional required.

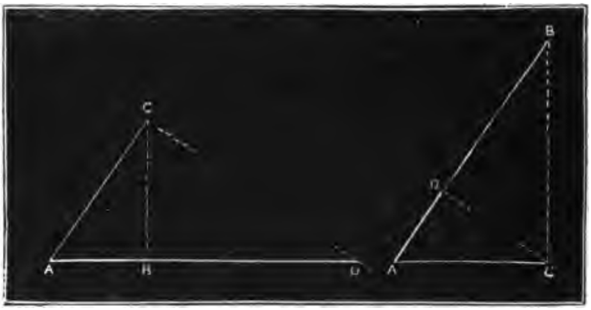


Fig. 76.

Reason.—By Theor. 16, A C is a mean proportional between A B and A D; or A D is a third proportional to A B and A C.

EXERCISE.

The hypothenuse of a right-angled triangle measures 3 inches, and its acute angles measure 30° and 60°; a perpendicular being drawn from the right angle to the hypothenuse, find third proportionals to the hypothenuse and each of its segments, and measure them.—*Ans.* $\frac{11}{16}$ inch, and $\frac{4}{16}$ inch.

107. PROBLEM 33.—*To find a mean proportional between two given straight lines.*

METHOD I.—On a straight line B C, Fig. 77, set off B A and A C equal to the given lines; on B C describe a semicircle B D C, and from A draw A D perpendicular to B C, meeting the circumference in D; then A D is the required mean proportional.

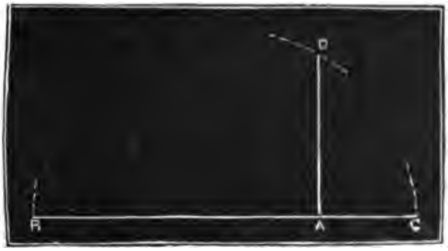


Fig. 77.

Reason.—If A D, D C be drawn, the angle A D C is a right angle (Theor. 14); therefore A D is a mean proportional between B A and A C (Theor. 16).

METHOD II.—Upon A B, Fig. 78, the longer of the two lines, describe a semicircle A D B; set off A C equal to the shorter of the given lines, and from C erect the perpendicular C D to meet the circumference in D; then the straight line A D shall be the required mean proportional.

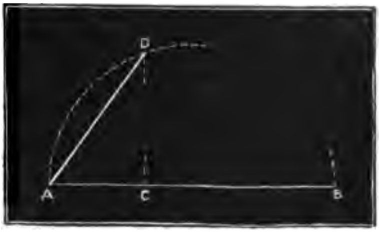


Fig. 78.

Reason.—As before, A D B is a right angle, and therefore (Theor. 16) A D is a mean proportional between A B and A C.

EXERCISE.

Find a mean proportional between the side of a square and its diagonal, the length of the side being $2\frac{1}{4}$ inches.—*Ans.* $2\frac{38}{46}$ inches.

108. Problem 34.—*To divide a given line similarly to a given divided line.*

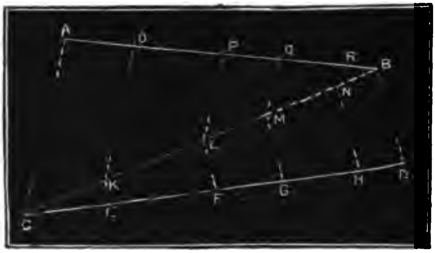


Fig. 79.

Let A B, Fig. 79, be the given line to be divided, and C D the divided line, divided into the parts C E, E F, F G, G H and H D; join B C; draw lines parallel to B D through the points H, G, F, and E, intersecting B C in the points N M L and K; again draw parallels to A C through the points K, L, M, and N, intersecting A B in the points O P Q and R; then A B will be divided similarly to C D.

Reason.—By Theor. 17, C B is divided similarly to C D, and A B is divided similarly to C B; therefore A B is divided similarly to C D.

Check.—The problem may be solved in a like manner by joining A D.

109. Problem 35.—*Two straight lines being given which would intersect if produced far enough, to draw lines through given points which would, if produced, pass through the same point of intersection.*

Let A B and C D, Fig. 80, be the two straight lines in the same plane, which are not parallel, and would, consequently, meet if produced, and let P be a given point; through P draw a straight line A C, not parallel to either of the given lines, and let it cut them in the points A and C; at a distance from A C, as great as may conveniently be taken, draw a straight line, B D, parallel to it (Prob. 11), cutting the given lines in the points B and D; join A D; through P draw P E parallel to D C, meeting A D in E; through E draw E F parallel to A B meeting B D in F; then the straight line P F will pass through the point of intersection of A B and C D.

Reason.—The line B D is divided similarly to the line A C (Prob. 34), and hence

$$A P : P C :: B F : F D.$$

Now let G denote the point in which the lines A B and P F meet when produced; then will the triangles G A P and G B F be equiangular (Theor. 9), and have the sides about their equal angles proportionals (Theor. 18). Therefore—

A P : B F :: P G : F G

and A P : A P — B F :: P G : P F

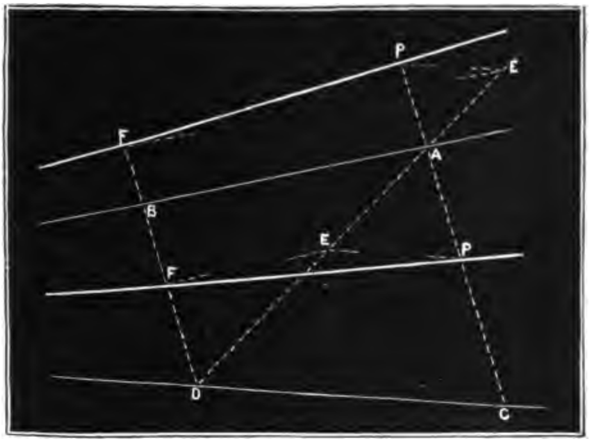


Fig. 80.

In like manner, if H denote the point in which the lines P F and C D meet when produced

P C : P C—F D :: P H : P F.

But since A P : P C :: B F : F D

A P : A P—B F :: P C : P C — F D

Therefore P G : P F :: P H : P F,

and therefore P G is equal to P H; so that G and H coincide, and the lines A B, C D, and P F meet in the same point.

Check.—The problem may be solved in like manner by joining B C, and drawing lines first parallel to A B and then to C D.

EXERCISE.

The horizontal line in a picture being given, and the perspective line representing the top of a house front, to draw the perspective lines for the windows, &c.

Let A B, Fig. 81, be the horizontal line, C D the top of the face of the building, and C A its front edge, and let the heights of the bottoms and tops of the windows be marked at E, F, G, R; take a vertical line close to the edge of the paper, produce A B, C D, to meet it at H and T, and by the preceding problems divide H T at M, N, P, Q, similarly to A C; then the lines E M, F N, G P, and R Q, will give the bottoms and tops of the windows.

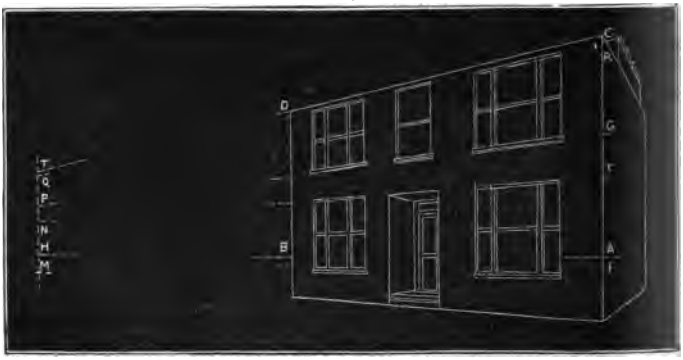


Fig. 81.

DIVISIONS OF LINES INTO EQUAL PARTS.

110.—The mode of bisecting a line has already been given, and by continued bisection a line can be divided into 4, 8, 16, &c., equal parts.

111.—PROBLEM 36.—*To trisect a given straight line A B.*

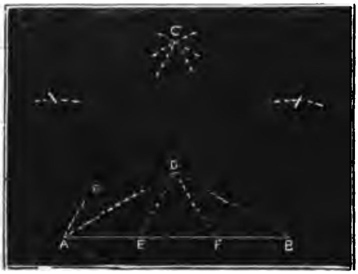


Fig. 82.

METHOD I.—On A B Fig. 82, describe the equilateral triangle A B C; bisect the angles at A and B by lines intersecting in the point D, and through D draw parallels to C A and C B cutting A B in the points E and F; then will A B be divided at E and F into three equal parts.

Reason. — The triangle D E F is equiangular (Theor. 9) to the triangle A B C, and therefore equilateral (Theor. 4); the angle A D E is equal to the angle D A C (Theor. 8), and, consequently, to the angle D A E; therefore A E is equal to E D, that is to E F; and in like manner B F is also equal to E F.

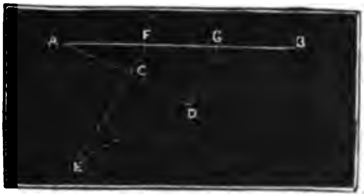


Fig. 83.

METHOD II.—Draw A D, Fig. 83, making any angle with A B; and set off on it equal distances, A C and C D; join B D, and produce it, making D E equal to D B; through E and C draw a straight line, cutting A B in F; and through D draw a parallel to E F, cutting A B in G; then A B will be trisected in the points F and G.

Reason.—C F being parallel to the side D G of the triangle A D G, A F is to F G as A C to C D (Theor. 15); but A C is equal to C D; therefore also A F is equal to F G. Again, G D being parallel to F E, a side of the triangle B F E, F G is to G B as E D to D B; but E D is equal to D B; therefore also F G is equal to G B; therefore A F, F G, and G B, are equal to each other, and the line A B is trisected in F and G.

METHOD III.—From A and B, Fig. 84, draw A C and B D parallel to one another; on these lines set off A E, E C, B F, F D, all equal to each other: join D E, and C F, intersecting A B in the points G and H; then A B shall be divided into three equal parts in the points G and H.

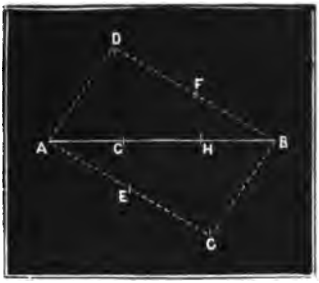


Fig. 84.

Reason.—D F and E C being equal and parallel straight lines, D E and C F are also (Theor. 10) equal and parallel, and therefore (Theor. 15) A G is to G H as A E to E C; and as A E is equal to E C, A G is also equal to G H. In like manner B H is equal to H G; and, therefore A G, G H, and H B, are equal to one another, and A B is trisected in the points G and H.

EXERCISES.

(1.) Draw a line 2⅛ inches long, and trisect by Method I.
(2.) Draw a line 2¾ inchs long, and trisect it by Method II.
(3.) Draw a line 1·7 inches long, and trisect it by Method III.

112. **Problem 37.**—*To divide a straight line into any number of equal parts.*

Method I.—Let A B, Fig. 85, be the given line; draw a straight line A C, making any angle with A B; take any distance, and set it off along A C, from A to C, as many times as the number of parts into which A B is to be divided; through the divisions thus marked on A C draw parallels to B C, intersecting A B; then A B will be divided into the number of equal parts required.

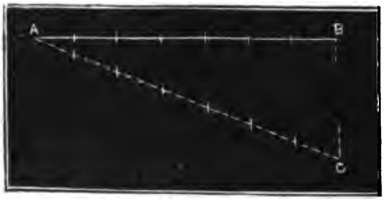


Fig. 85.

Reason.—A B is divided similarly to A C (Theor. 17).

Method II.—Draw A C, Fig. 86, making any angle with A B as before; set off on A C, from A to C, any distance as many times less one as the number of parts into which A B is to be divided; from A draw A D parallel and equal to B C; draw from D to the first division E on A C, a straight line, cutting A B in F; through the other divisions on A C draw parallels to D E, to cut the line A B; then AB shall be divided as required.

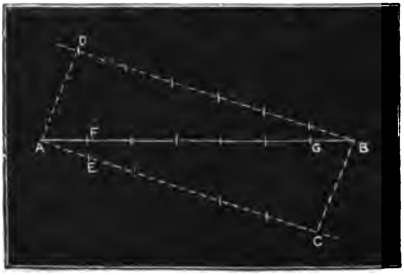


Fig. 86.

Reason.—Let C G be the last of the parallels to D F E; then (Theor. 17) A G is divided into the same number of equal parts as A C. Again, the triangle A D F being equiangular to the triangle B G C, and the side A D equal to the side B C, B G is also equal to A F, one of the equal parts into which A G has been divided.

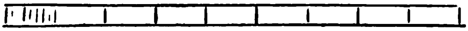
Exercises.

(1.) Take a line 3·3 inches long, and divide it into seven equal parts by Method I.

(2.) Take a line 2·74 inches long, and divide it into five equal parts by Method II.

CONSTRUCTION OF SCALES.

113. To represent within a limited compass plans or drawings of objects of a considerable extent, and to be able to estimate the real dimensions of the objects represented from the drawings representing them, it is necessary to take for the representation of each unit of linear measurement, a length bearing the same proportion to the unit represented, as the linear dimensions of the surfaces, on which the drawings are to be constructed, bear to those of the objects. Thus if it be desired to construct within a width of 10 inches, a map of a tract of country whose greatest width is 45 miles, each mile of actual distance must be represented on the paper by a length of $\frac{2}{9}$ of an inch, and consequently each furlong by $\frac{1}{36}$ of an inch. If then a line two inches long be divided into nine equal parts,



and one of these parts be subdivided into eight equal parts, and the primary divisions be taken to represent miles, and the subdivisions, furlongs, a scale will be formed, by means of which the representative distances between the points to be laid down on the map can be set off, and the map constructed; and again, by means of this scale, the actual distance between any two points represented in the map can be determined.

114. Such a scale as we have just described, in which two inches represent nine miles, is called a scale of 1 inch to $4\frac{1}{2}$ miles, or of $\frac{2}{9}$ of an inch to a mile.

Also since $4\frac{1}{2}$ miles contain 285,120 inches, and this distance is represented on the scale by 1 inch, it is called a scale of $\frac{1}{285120}$, and $\frac{1}{285120}$ is called the *representative fraction.*

115. Since the paper on which the drawings are constructed expands in moist weather, and contracts in dry, the scale upon which they are constructed should be laid down on the paper itself, so as to expand and contract with it. By this means whatever changes may take place in the hygrometric state of the atmosphere during the operation of constructing the drawings, all their points will be laid down in their proper relative positions, at their proper representative distances from each other, and the scale will at all times determine with accuracy the real distances between the points so laid down.

116. *The ordinary or simply divided scales* are most usually subdivided *decimally*, that is, a certain length being divided

into a number of equal parts, or primary divisions, the primary division at one extremity of the scale is subdivided into ten equal parts; so that each subdivision represents one-tenth of the distance represented by a primary division, or a primary division represents ten times the length represented by a subdivision.

117. On such decimally subdivided scales, the dimensions are taken off to two places of figures, which may be tens and units, or hundred and tens, or units and tenths, or any other two orders of figures, of which a figure in the one is ten times the value of the same figure in the other.

118. Simply divided scales are, however, frequently so subdivided as to designate two orders of units of measurement, miles and furlongs, feet and inches, &c. In this case the primary divisions represent the higher order of units, and at one extremity of the scale a primary division is subdivided into the same number of equal parts as the number of units of the lower order contained in one unit of the higher.

119. In constructing scales it must be borne in mind that by taking a short measurement and repeating it, the error in the measurement is multiplied in the whole length set off by as many times as the measurement is repeated; while by taking a long measurement and dividing it, the error in the measurement is divided among the equal parts thus formed. Such a length, therefore, as will suffice for the whole or the greater part of the scale should be taken, and divided first for the primary divisions; and the division at one extremity, usually at that on the left hand, should be subdivided as already explained.

120. In figuring the scales, the zero is not at the extremity of the scale, but at the end of the first or subdivided primary division, and the figures run from this point in one direction for the primary divisions, and in the other for the subdivisions.

EXAMPLES OF SIMPLY DIVIDED SCALES.

121. The following examples will illustrate the mode of proceeding.

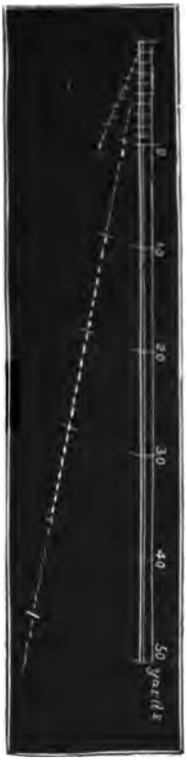
(1.) *To construct a scale to measure single yards, in which* 109 *yards shall be represented by* 6 *inches.*

Since the subdivisions are to represent single yards, the primary divisions must represent ten yards each, and the total length of the scale some multiple of ten yards. Let it be determined that it shall be figured to 50 yards, then it must contain altogether a sufficient length for six primary divisions. one of them being required for the subdivisions. Hence we have the following proportion to find the entire length of the scale,

109 : 60 : : 6 : 3·3 inches.

Take, therefore, a length of 3·3 inches (Fig. 87),* and divide it (Prob. 37) into six equal parts; each of these will represent 10 yards; subdivide the first division on the left hand into ten equal parts; each of these will represent one yard. Now rule a second line parallel to the first at about the fifteenth of an inch from it; mark the subdivisions, denoting single yards, by short strokes included between the parallel lines, with the exception of the fifth stroke, which is to be distinguished by being produced a short distance above the top line; while the primary divisions, each denoting ten yards, are to be marked by strokes projecting still further above the top line. Lastly, figure the primary divisions 10, 20, 30, 40, 50, from left to right, marking the stroke at the end of the first primary division 0, for the zero or commencement, both of the primary divisions and the subdivisions; and figure the subdivisions 10 from this zero point to the left-hand extremity of the scale.

Fig. 87.



To take off from the scale the length that will represent a certain number of yards less than 60, put one point of the compasses or dividers on the subdivision denoting the units in the number, and extend the other point of the compasses to the primary division denoting the tens; thus, to take off the representative length of 43 yards, extend the compasses from the third stroke on the left of the zero, to the fourth stroke on the right; for 27 yards, extend from the seventh stroke on the left of the zero to the second stroke on the right, and so on.

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* This length can be taken from the plain scale. See "Mathematical Instruments."

Since 6 inches represent 109 yards, 1 inch represents $18\frac{1}{6}$ yards, or $18\frac{1}{6} \times 36 = 654$ inches; and the representative fraction, which gives the ratio of the lengths on the scale to the lengths represented by them, is $\frac{1}{654}$.

(2.) *To construct a scale of* $\frac{1}{570240}$ *to represent miles.*

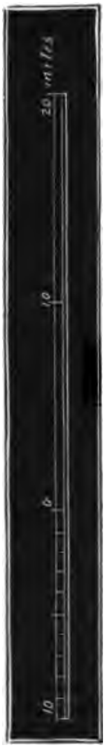

Fig. 88.

In this case the representative length of 30 miles is given by the proportion—

570240 : 1 : : 30 miles : $3\frac{1}{3}$ in.

Take, therefore, a length of $3\frac{1}{3}$ inches (Fig. 88); divide it into three primary divisions, each to represent 10 miles; and subdivide the left-hand division into ten equal parts to represent single miles.

The scale is finished in a similar manner to the last, and figured from 0 to 20 on the right-hand of the zero point, and from 0 to 10 on the left of the zero.

(3.) *To construct a scale of half an inch to a foot to denote feet and inches.*

On this scale 3 inches will represent 6 feet; take, therefore, 3 inches (Fig. 89), divide it into 6 equal parts to represent feet, and subdivide one of them into 12 equal parts to represent inches.

To take off the representative length of a number of feet and inches from this scale, extend the compasses from the subdivision denoting the number of inches, to the primary division denoting the number of feet: thus to take off 4 feet 7 inches, extend the points of the compasses from the seventh subdivision on the left of the zero, to the fourth primary division on the right of the zero.

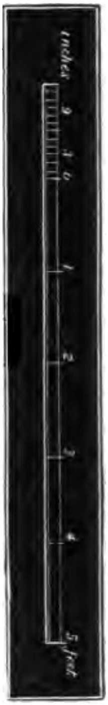

Fig. 89.

(4.) *To construct a scale of* $\frac{1}{30}$*, to represent metres and decimetres, the metre being 39·37 inches, and the limits of the paper not allowing the entire length of the scale to exceed 3½ inches.*

The above limits will confine the entire length of the scale to the representative length of 4 metres; and, 50 metres being represented by 1 metre, or 39·37 inches, we have the following proportion to determine the representative length of 4 metres—

50 : 4 :: 39·37 : 3·15

Take, therefore, a length of 3·15 inches (Fig. 90) and divide it into four equal parts to represent metres; subdivide the extreme division on the left into 10 equal parts to represent decimetres; figure the primary divisions from 0 to 3 on the right of the zero, and the subdivision from 0 to 10 on the left.

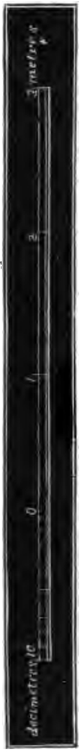

Fig. 90.

Diagonal Scales.

122. In the simply divided scales, as has been seen, two places of figures, or two orders of units, are represented; but if it be desired to proceed further, and represent three places of figures, or three orders of units, a second subdivision becomes necessary. This may be accomplished by the diagonal method of division, which we proceed to explain.

Let *a b*, Fig. 91, represent a distance to be divided: on *a b* describe a rectangle* *a b c d*, the sides *a d* and *b c*, consisting of as many equal parts of any convenient length as the number of parts into which *a b* is to be divided: through the extremities of each of these parts draw parallels to *a b*; and intersect them by the diagonal *a c*; then will this diagonal recede from *a d*, at each successive intersection, by one of the desired parts until at *c* it has receded through the entire distance *c d* or *a b*. Thus if *a d* be divided into eight equal parts, *e f* will be one-eighth of *a b*; *g h*, two-eighths; *k l*, three-eighths, and so on.

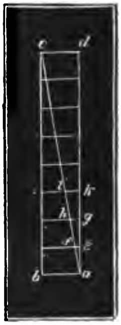

Fig. 91.

Examples of Diagonal Scales.

123. The application of this method of division to the construction of scales will be best understood by example.

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* Any parallelogram would do; but a rectangle is to be preferred.

Let it be required to construct a scale so that 5¼ inches shall represent 1,000 *feet, and let it be divided and subdivided until single feet are represented on it.*

To make the entire length of the scale the representative of 600 feet, we have the following proportion—

1,000 : 600 : : 5¼ : 3·15

Take, therefore, a line A B, Fig. 92, 3·15 inches long, and divide it into six equal parts; these primary divisions will represent 100 feet each; subdivide the left-hand division into ten equal parts: each of these subdivisions will represent 10 feet. So far the process has been the same as for the simply divided scales. Now for the further divisions to represent single feet. Rule ten lines parallel to the line already divided; through each of the primary divisions draw perpendiculars, intersecting all the parallel lines at right angles; through the ninth subdivision *c*, draw a diagonal, *c a*, to meet A *a*, the extreme perpendicular on the left-hand, at its point of intersection *a*, with the tenth parallel *a b*· through the other subdivisions, and the zero on the divided line, draw diagonals parallel to *c a;* then will each of the diagonals separate further and further from the perpendicular through the zero point by one-tenth of a subdivision as they reach each successive parallel, going upwards, from the divided line A B. Now the distance represented by a subdivision is 10 feet; consequently the diagonals recede from the perpendicular at each successive parallel by the distance representing one foot. Hence the problem is solved.

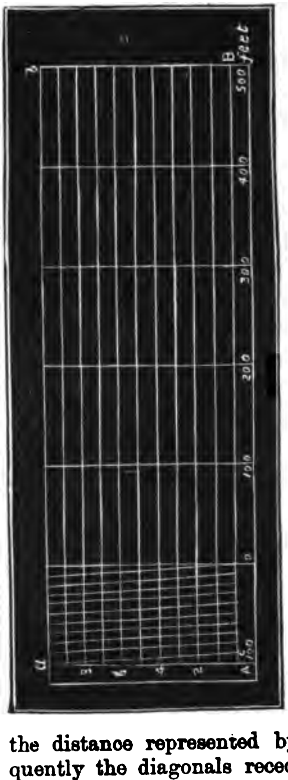

Fig. 92.

124. To take off the length representing a distance of any number of feet from this scale.

(1.) When the distance contains only hundreds and tens, but no units, the required length is to be taken off on the divided line A B, as in the simply divided scales before described, by extending from the subdivision denoting the tens to the primary division denoting the hundreds.

(2.) When the distance contains units, the required length is to be taken off on the parallel denoted by the units, by extending from the diagonal passing through the subdivision denoting the tens to the perpendicular passing through the primary division denoting the hundreds.

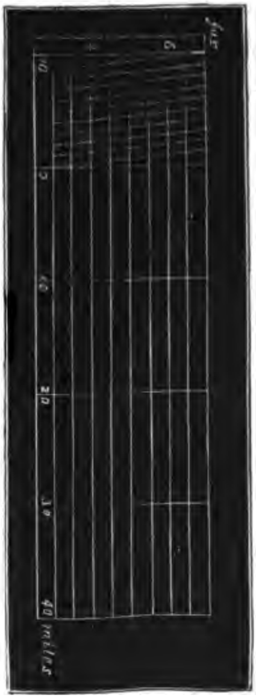

Fig. 93.

Thus, to take off the length to represent 350 feet, extend from the fifth subdivision on the divided line A B to the third primary division on the same line; and to take off 357 feet, extend on the seventh parallel from the diagonal passing through the fifth subdivision to the perpendicular passing the third primary division.

125. *A distance of* 50 *miles is to be represented by* 3 *inches: construct a scale with diagonal divisions to show furlongs.*

Take a length of 3 inches (Fig. 93), divide it into five equal parts, each to represent 10 miles; subdivide the left-hand part into ten equal parts, each to represent one mile; rule eight parallels to the line thus divided; draw perpendiculars through the primary divisions, and diagonal through the subdivision in the manner explained above; then the scale will be constructed as desired.

To take off the length to represent a given distance from this scale, extend on the parallel denoting the furlongs, from the diagonal passing through the subdivision denoting the units of the miles, to the perpendicular passing through the primary division denoting the tens; thus to take off the length to represent 27 miles 3 furlongs, extend on the third parallel from the diagonal passing through the seventh subdivision to the perpendicular passing through the second primary division.

COMPARATIVE SCALES.

126. The standard of linear measure being arbitrary, and different countries making use of different standards, it becomes necessary, in order to render the dimensions of the maps prepared for one nation intelligible to another, to construct for these maps new scales, adapted to the standards of measurement made use of by the latter nation. Thus to make a map prepared for the use of the French or the Prussians, of equal use to the Englishman, it must have a scale of English linear measures prepared for it; and, conversely, to make the dimensions represented on an English map obvious to a Frenchman, it must have constructed for it a scale of French linear measures.

127. Scales constructed according to different standards of measurement for the same map or plan, are called *comparative* scales.

128. The representative fraction (113), indicating the ratio of the representative lengths to the distances represented by them, is manifestly quite independent of the unit of measurement; consequently comparative scales have the same representative fraction. Hence, if the representative fraction of a scale be either given or computed, any number of scales comparative to it can be constructed by means of this fraction. They may also be constructed without the assistance of this fraction from the following considerations:—

(1.) The numbers of units representing a certain distance are inversely as the lengths of the units. Thus the number of feet in a certain distance is to the number of yards in the same distance as 3 to 1.

(2.) The lengths representing the same numbers of different units are to each other as the lengths of the units themselves. Thus the English yard consisting of 36 inches, and the French metre of 39·37 inches, the lengths representing any the same number of yards and metres are to one another as 36 to 39·37.

(3.) The lengths representing different numbers of different units are to each other in the ratio compounded of the numbers of the units and of their lengths. Thus the length representing 60 yards is to the length representing 50 metres as 60×36 is to $50 \times 39 \cdot 37$.

EXAMPLES OF COMPARATIVE SCALES.

129. *The maps of the French Ordnance Survey are constructed on a scale of* 12·5 *millimetres to the kilometre, or* $\frac{1}{80000}$; *it is required to construct a scale, comparative to this, of English miles and furlongs.*

80,000 : 1 : : 4 miles : 3·17 inches.
Take, therefore, a length of 3·17 inches (Fig. 94), divide it into four equal parts which will each represent a single mile; subdivide the left-hand part into eight equal parts, to represent furlongs; then the desired scale will be formed; and by it the distances between places represented in a French Ordnance map can be measured in English miles and furlongs.

130. *The maps of the Ordnance Survey of Great Britain are constructed on scales of* $\frac{1}{2500}$ *or* 25·344 *inches to the mile for the parishes,* 6 *inches to the mile for the counties, and* 1 *inch to the mile for the whole country; it is required to construct scales of French kilometres and parts of a kilometre comparative to the above three scales.*

(1.) On the scale of $\frac{1}{2500}$, a distance of 2,500 metres would be represented by a length of one metre; hence to find the length to represent a distance of 600 metres, we have the following proportion—

2,500 : 600 : : 1 : ·24

Take, therefore, from a French plain scale, a length of 240 millimetres (Fig. 95), divide it into six primary divisions, each representing 100 metres; subdivide the left-hand division into ten equal parts, each representing 10 metres; and, if desired, it may be divided still further diagonally to represent single metres.

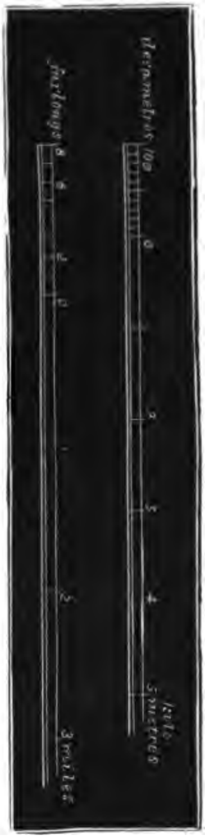

Fig. 94.

If unprovided with a French scale of millimetres, the equivalent measurement in inches and decimals of an inch must be taken from an English plain scale. Thus, 39·37 inches being the equivalent for a metre, $39{\cdot}37\frac{240}{1000} = 9{\cdot}45$ inches is the equivalent for 240 millimetres.

(2.) An English mile contains 1,760 yards, and a kilometre contains 1093·6 yards. Hence, to find the length to represent a distance of 1·1 kilometres or 1,100 metres, we have the following proportion:—

$$1760 : 1093{\cdot}6 \times 1{\cdot}1 :: 6 : 4{\cdot}1$$

Take, therefore, a length of 4·1 inches (Fig. 96); divide it into eleven equal parts, each representing 100 metres, and sub-

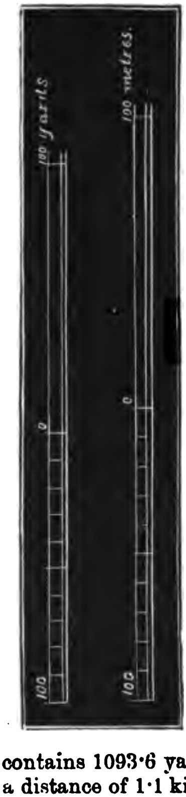

Fig. 95.

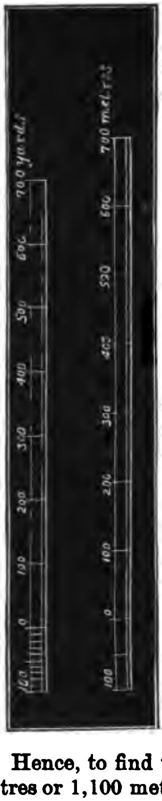

Fig. 96.

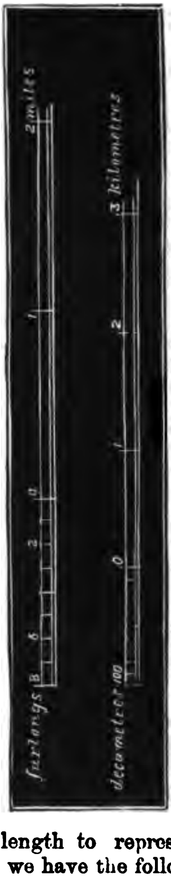

Fig. 97.

divide the left-hand division into ten parts, each representing 10 metres.

(3.) On the one-inch scale, 11 inches represent 11 miles. Hence, to find the length to represent 11 kilometres, we have the proportion:—

1760 : 1093·6 : : 11 : 6·835

Take, therefore, a length of 6·835 inches (Fig. 97); divide it into eleven equal parts, each representing one kilometre, and subdivide the left-hand part into ten equal parts, each representing 100 metres.

131. With respect to the extent to which a scale should be carried, no definite rule can be given, so much depends on the space available for its reception. It is, however, usually made to consist of either six or eleven of the primary divisions, so as to have either five or ten of them besides that which is subdivided. If, however, it be easier to compute or to measure the length for five or ten primary parts than for six or eleven, the shorter length may be taken and divided into five or ten equal parts, and then one of these parts may be added to the length, to compensate for the part subdivided.

132. EXERCISES ON CHAPTER III.

(1.) Divide a line 5½ inches long into seven equal parts.

(2.) Divide a line 3·3 inches long into four parts that shall have their lengths in the proportions of 3, 5, 7, and 11.

(3.) Construct a square, A B C D, upon a line, A B, 4 inches long; on the side A D take a point E, about ·23 inches from A, and a point F, about ·15 inches from D; join B E and C F; on the side B C, produced to G, take the points H, and K, 1 inch and 2½ inches from B, and the point G, 1 inch from C; draw straight lines through the points H K and G, so that they and the lines B E and C F, if produced, would all meet in the same point.

(4.) A field is surrounded by a hedge, whose plan forms an irregular hexagon, A B C D E F. The distance from the corner A to the corner D is 255 yards, and is to be represented by a straight line 4·2 inches long. At G, 40 yards from A, B G F intersects A D at right angles, and G B and G F are 45 and 55 yards respectively. At H, 73 yards from D, C H E also intersects A D at right angles, and H C and H E are 103 yards and 142 yards respectively. Draw a diagonal scale for the figure so that single yards may be measured by it, and ascertain the length of the hedge. *Ans.* 734 yards.

(5.) Draw a plain scale of English miles and furlongs, comparative to a scale of 3 inches to a Saxon mile, and give the representative fraction.

A Saxon mile is equivalent to 9923·32 English yards.

Ans. $\frac{1}{119079{\cdot}84}$.

CHAPTER IV.

ON CIRCLES AND LINES TANGENTIAL.

THEOREMS.

133. THEOR. 19.—A straight line which bisects a chord of a circle at right angles passes through the centre. (Eu. III., 1.)

134. THEOR. 20.—A line which touches a circle is at right angles to the diameter through the point of contact; and the converse. (Eu. III., 16, 18.)

135. THEOR. 21.—When two circles touch, the straight line which joins their centres passes through the point of contact. (Eu. III., 11 and 12.)

136. THEOR. 22.—Angles in the same segment of a circle are equal to one another. (Eu. III., 21.)

137. THEOR. 23.—If a straight line touch a circle, and from the point of contact a straight line be drawn cutting the circle, the angles which this line makes with the line touching the circle shall be equal to the angles which are in the alternate segments of the circle. (Eu. III., 32.)

138. THEOR. 24.—If from a point without a circle lines be drawn cutting the circle, and also a line touching it, the rectangles contained by the whole lines which cut the circle and the parts of them without the circle shall be equal to each other, and also to the square of the line which touches the circle. (Eu. III., 36.)

138*. THEOR. 25.—If from a point without a circle there be drawn two straight lines, one of which cuts the circle, and the other meets it; and if the rectangle contained by the whole line which cuts the circle, and the part of it without the circle, be equal to the square of the line which meets it, the line which meets shall touch the circle. (Eu. III., 37.)

PROBLEMS.

139. PROBLEM 38.—*To draw a diameter of a given circle* A B C.

Open the compasses to any convenient distance; place one leg on any point, A, Fig. 98, of the circumference and strike arcs on both sides of it; with the same radius, from a second point, C, in the circumference, distant about three-fourths of this radius from the first, strike arcs intersecting those before described in the points D and E; then the straight line D B E drawn through D and E will pass through the centre, and B D F the part of it intercepted by the circumference, will be a diameter.

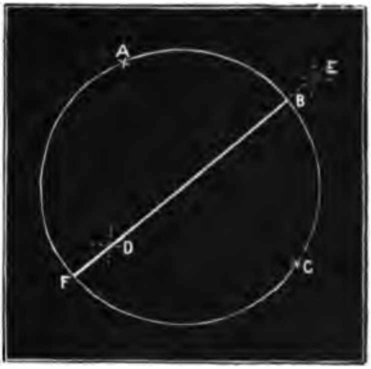

Fig. 98.

Reason.—By the above process B D bisects at right angles the chord A C, and passes therefore through the centre (Theor. 19).

140. **Problem 39.**—*To find the centre of a given circle.*

Method I.—Draw a diameter by the preceding problem and bisect it.

Method II.—Open the compasses to any convenient extent; place one foot on any point, A, Fig. 99, of the circumference, and from this point as centre describe an arc, cutting the given circle in the points B and C; from the centre A, with radius equal

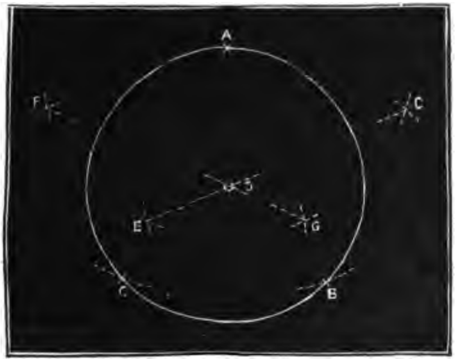

Fig. 99.

to about three-fourths of A B or A C, describe a circle D G E F; with the same radius strike arcs from the points B and C, as centres, intersecting the circle D G E F in the points D, E and F, G; then O, the point of intersection of the straight lines D E and F G, will be the centre of the given circle A B C.

Reason.—Each of the lines D E and F G passes (Theor. 19) through the centre, which must therefore be at their point of intersection.

EXERCISE.

Describe circles, taking care to place the point of the compasses on a horn centre, or small piece of cardboard, so that the centres from which the circles are described shall not be marked on the paper; then find their centres by the methods just given.

141. PROBLEM 40.—*To draw a circle through three given points* A B C.

From A and B, Fig. 100, strike arcs with any the same radius intersecting in D and E; from B and C with any the same radius strike arcs intersecting in F and G; draw straight lines through D and E, and through F and G, intersecting in O; then O is the centre of the required circle; and a circle described from this centre with distance between it and one of the points will pass through the other two.

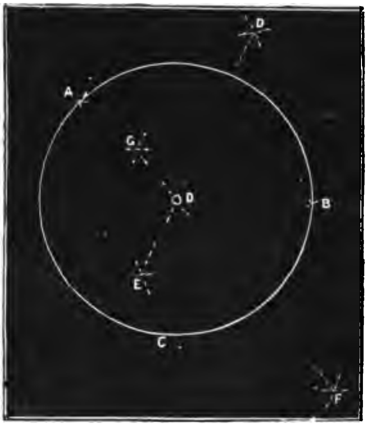

Fig. 100.

Reason.—The centre of every circle passing through the points A and B is on the line D E, and the centre of every circle passing through B and C is on F G (Theor. 19); consequently the point O in which these lines intersect is the centre of the circle passing through the three points A, B, and C.

EXERCISES.

(1.) Construct the triangle, whose sides are 3·2 inches, 4·1 inches, and 5 inches. Describe a circle about this triangle, that is passing through its angular points.

(2.) Describe a rhombus, whose sides shall be 3 inches long, and include angles of 60° and 120°. Describe circles through every three of its angular points.

142. PROBLEM 41.—*To draw a straight line which shall touch a given circle in a given point* P. (Fig. 101).

Through P draw P Q at right angles to the line P O passing through P and the centre O of the circle; P Q will be the tangent required (Theor. 20).

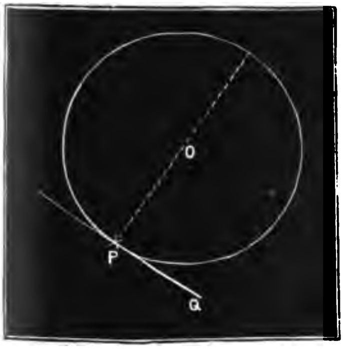

Fig. 101.

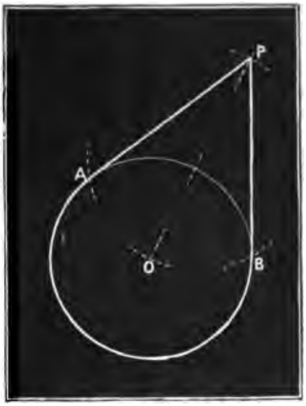

Fig. 102.

143. PROBLEM 42.—*To draw tangents to a circle from a given point* P *without it.*

Join P and O, Fig. 102, the centre of the circle; with O P as diameter, describe a circle cutting the given circle in the points A and B, and join P A and P B; then P A and P B shall be the tangents required.

Reason.—O P being a diameter of the circle A P B O, P A O and P B O are angles in semicircles, and are therefore right angles (Theor. 14); hence P A and P B are tangents (Theor. 20).

144. PROBLEM 43.—*To draw to a given circle tangents which shall be parallel to a given straight line.*

Through the centre O, Fig. 103, of the given circle, draw O A perpendicular to the given line, cutting the given circle in the points P and Q; then P R and Q S drawn through P and Q parallel to the given line, or perpendicular to O A, will be the tangents required.

Reason.—Obvious.

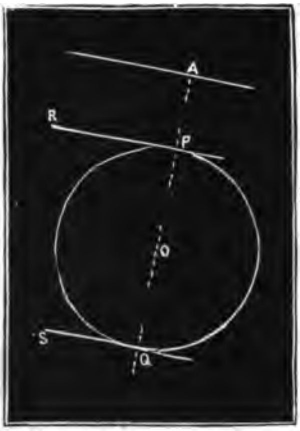

Fig. 103.

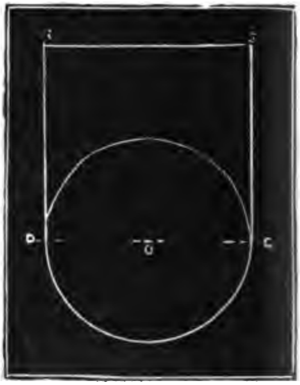

Fig. 104.

145. **Problem 44.**—*To draw to a given circle tangents which shall be perpendicular to a given straight line.*

Through the centre O, Fig. 104, of the given circle, draw a parallel to the given line, cutting the circle in the points P and Q; then P R and Q S, drawn through P and Q perpendicular to P Q and to the given line R S, will be the tangents required.

Reason.— Obvious.

146. **Problem 45.**—*To draw to a given circle tangents which shall make a given angle with a given straight line.*

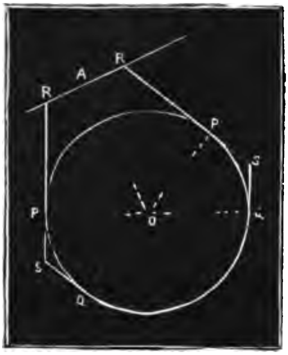

Fig. 105.

From the centre O, Fig. 105, of the given circle, draw O A perpendicular to the given straight line; through the centre O, draw the diameter P O Q, making with O A the angle A O P equal to the given angle; through P and Q draw P R and Q S at right angles to P Q, then P R and Q S shall be the tangents required.

Reason.—P R or Q S and the given line being respectively perpendicular to P O and O A, will contain the same angle.

EXERCISE.

Draw a circle of 1 inch radius and a straight line without it. Then draw tangents to the circle making angles of 30° with the line.

147. PROBLEM 45.—*To draw straight lines which shall touch two given circles; (1) each on the same side; (2) each on alternate sides.*

(1.) Join O, O′, Fig. 106, the centres of the given circles, cutting their circumferences in the points C and D; on O O′, as diameter, describe a circle; from C set off C E towards the centre O, equal to O′ D; with centre O and radius O E describe a circle, cutting the circle described on O O′ in the points F; through O and F draw O F A to meet the circumference of the given circle A C A in A; through O′ draw O′ B parallel to O A; join A B; then A B will touch both circles on the same side.

Reason.—The angle O F O′ being the angle in a semicircle, is (Theor. 19) a right angle; therefore the angle A F O′ is also a right angle. Now, A F and B O′ being equal and parallel, the figure A F O′ B is (Theor. 10) a parallelogram, and one of its angles at F being a right angle, all its angles are right angles (32); hence the angles at A and B are right angles, and therefore (Theor. 20) A B touches both the circles.

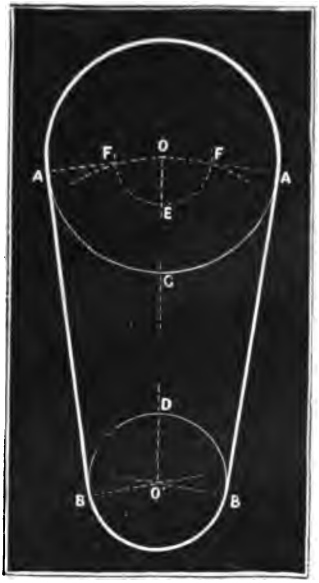

Fig. 106.

(2.) Join O O′, Fig. 107, and on O O′ as diameter, describe a circle as before; from C set off C E, away from the centre O, equal to O′ D; with centre O and radius O E describe a circle cutting the circle described on O O′ in the points F; through O and F draw O A F, cutting the circumference of the given circle A C A in the point A; through O′ draw O′ B parallel to O A; join A B; then A B will touch both circles on alternate sides.

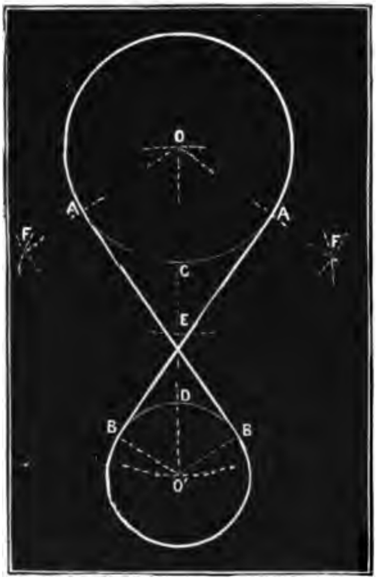

Fig. 107.

Reason. — Similar to that given above.

EXERCISES.

(1.) Draw two circles with radii of 2 inches and 1 inch, respectively, from centres 2½ inches apart, and connect them by tangent lines.

(2.) Draw two circles with the same radii as in the preceding question, from centres 3½ inches apart, and connect them by cross tangents.

148. PROBLEM 46.— *To draw a circle of given radius to touch a given straight line in a given point.*

From the given point A, Fig. 108, draw a perpendicular A O; make A O equal to the given radius; then the circle described from centre O, with the given radius O A, will touch the given line in the given point.

Reason.—(Theor. 20.)

EXERCISE.

Draw a line A B 1½ inches long, and continue it in a curve by drawing a circular arc with 1 inch radius to touch it at B.

149. PROBLEM 47.—*To draw a circle which shall pass through a given point, and touch a given straight line in a given point.*

Bisect at right angles the line A B, Fig. 109, joining the given point A, through which the circle is to pass, with the given point B on the given line; and let the bisecting line D O intersect in the point O, the perpendicular to the given line drawn from the given point B upon it; then the circle described from centre O, with radius O A, will touch the given straight line in the given point B.

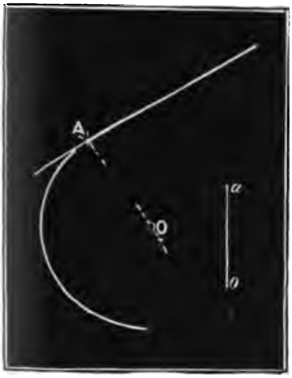

Fig. 108.

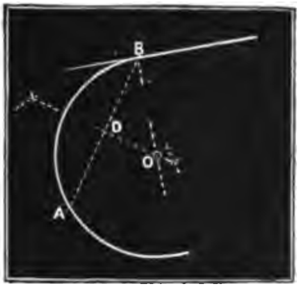

Fig. 109.

Reason.—The sides A D, D O, are equal to the sides B D, D O, each to each, and the right angle A D O to the right angle B D O; therefore O A is equal to O B (Theor. 1), and the circle passes through B; then, since the given line is at right angles to the radius O A, at its extremity it (Theor. 20) touches the circle.

Exercise.

Describe a square with sides of 2 inches, and draw a circle to pass through one of its angular points, and touch the middle point of a side.

150. Problem 48.—*To draw a circle with a given radius to pass through a given point, and touch a given straight line.*

Draw a straight line D C, Fig. 110, parallel to the given straight line, at a distance from it equal to the given radius (Prob. 12); from the given point A, as centre, with the given radius, describe an arc cutting the line D C in the points C and D; then circles described from centres C and D, with the given radius, will pass through the point A, and touch the given line P Q.

Reason.—If C P be drawn perpendicular to the given line C P is equal to the given radius, and so is C A; therefore the circle passes through A and P, and touches the given line P Q, since C P Q is a right angle.

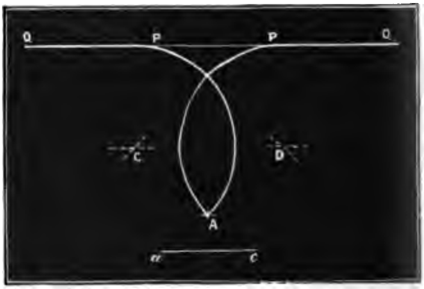

Fig. 110

EXERCISE.

Describe an equilateral triangle with sides 1½ inches long; and draw a circle with a radius of 1 inch to pass through its vertex and touch its base.

151. PROBLEM 49.—*To draw a circle with a given radius to touch two given straight lines.*

At distances from the given lines equal to the given radius, draw lines parallel to them, intersecting one another in the point O, Fig. 111; then O is the centre of the required circle.

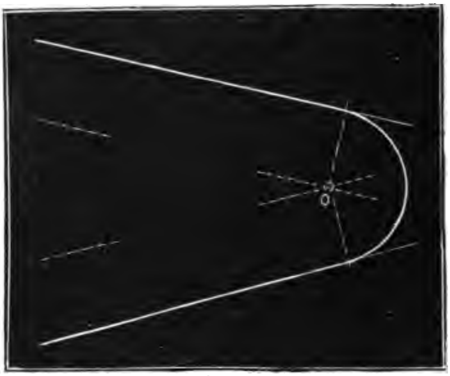

Fig. 111.

Reason.—Perpendiculars drawn from O upon the given lines will be equal to the given radius.

EXERCISE.

Draw two lines inclined to one another at an angle of 30°, and connect them by a circle with a radius of ⅛ inch, touching them both.

152. **PROBLEM 50.**—*To draw circles to pass through two given points, and touch a given straight line.*

1st CASE.—When the straight line joining the two given points, A, B, Fig. 112, is parallel to the given line. Bisect A B at right angles by a straight line C G, intersecting the given line in the point G; bisect A G at right angles by a straight line intersecting C G in O; then O is the centre of the required circle.

Reason.—O (Prob. 40) is the centre of the circle passing through the three given points A, B and G; and O G being at right angles to the given line, the line and the circle touch one another.

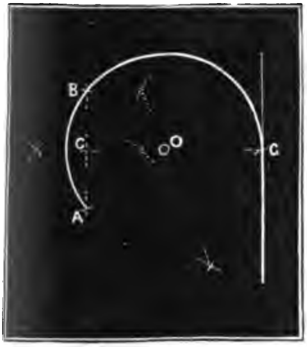

Fig. 112.

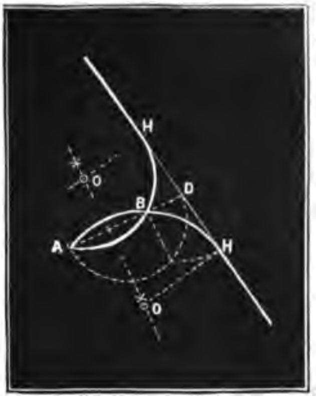

Fig. 113.

2nd CASE.—When the straight line joining the two points, A, B, Fig 113, is not parallel to the given line. Join A B and produce it to meet the given line in the point D; find a mean proportional between A D and D B (Prob. 33), and set it off on the given line from D to H; bisect A B at right angles by the straight line O O, and from H draw H O at right angles to H H; then the points O O will be the centres of the required circles.

Reason.—Since D H is a mean proportional between A D and D B, the square on D H is equal to the rectangle A D, D B; therefore (Theor. 24) the circle which passes through the three points A, B, H, touches the straight line H H. The centre of this circle must be (Theor. 19) on the line O O and also (Theor. 20) on the line O H; therefore it must be at O, the point of intersection of O O and H H.

153. **Problem** 51.—*To draw circles to pass through a given point and touch two given straight lines.*

Draw O O, Fig. 114, bisecting the angle contained by the two given lines H H; through the given point A draw A C B perpendicular to O O, and make C B equal to C A; then the circle which passes through the two points A, B, and touches one of the given straight lines, will also touch the other. Hence the centres are found as in the preceding problem.

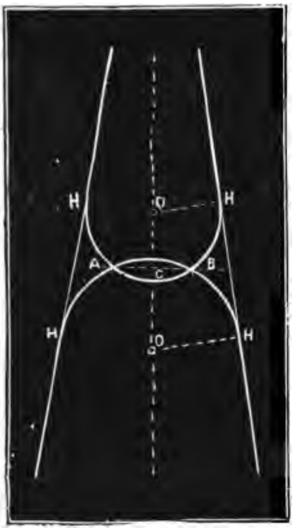

Fig. 114.

Reason.—Since the centres must be equally distant from both lines, they must be on the line O O, bisecting the angle between them; therefore A B is a chord at right angles to the diameter, and (Theor. 19) B is a point on the circumference.

Exercises.

(1.) The two sides A B, A C, of a triangle are each 2 inches long, and contain an angle of 40°; describe the triangle, and from B draw B D perpendicular to A C. Draw circles to pass through the points A, D, and touch the base B C, or this base produced.

(2.) Construct the same triangle and perpendicular as in last exercise, and draw circles to pass through the point D, and touch A B and B C.

154. **Problem** 52.—*To draw circles which shall have their centres on a given line* O O, *pass through a given point* A *on this line, and touch another given line* B B.

Through the given point A, Fig. 115, draw A C at right angles to O O, to meet the line B B in the point C; set off C B equal to C A, and through the points B, draw B O at right angles to B B; then the points O will be the centres of the required circles.

Check.—O C bisects the angle A C B.

Reason.—The right-angled triangles O A C and O B C have the hypothenuse O C common; therefore (Theor. 12) the squares on O B, B C, are equal to the squares on O A, A C. Hence, C B being equal to C A, O B is equal to O A; and, since the angles at A and B are right angles, the circles touch both the lines A C and B C.

To draw circles to touch two given straight lines, and pass through a given point on the line bisecting the angle between them is a case of this problem, since the centres must be on the bisecting line.

EXERCISES.

(1.) Describe an isosceles right-angled triangle with sides of 1·8 inches; and describe a circle from a centre on the hypothenuse, to pass through one of its extremities and touch a side of the triangle.

(2.) Draw two straight lines inclined to one another at an angle of 30°; bisect this angle, and draw a circle, to touch the two lines, and pass through a point on the bisecting line, at 3 inches distance from the angular point.

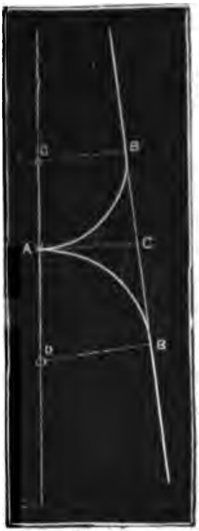

Fig. 115.

155. **PROBLEM 53.**—*To describe circles from a given centre to touch a given circle.*

Draw a straight line through A, Fig. 116, the given centre, and B, the centre of the given circle, to intersect the circumference of this circle in the points C and D; then the circles described from the centre A, with radii A C and A D, will touch the given circle.

Reason.—When two circles touch one another, the straight line which joins their centres passes through the point of contact. (Theor. 21.)

When the given point is within the given circle, in both cases one of the circles touches the other internally; but when the given point is without the given circle, in one case one circle touches the other internally, and in the other case the circles touch one another externally.

EXERCISES.

(1.) Describe a circle with a radius of ·7 inch; draw a tangent to this circle. From a point on the tangent, 1 inch distant from the point of contact, describe circles to touch the circle first described.

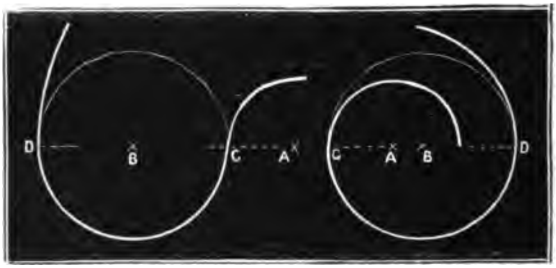

Fig. 116.

(2.) Describe a circle, and draw its tangent as in the preceding exercise; from the point of contact draw a straight line, making an angle of 60° with the tangent. From a point on this line, ½ inch distant from the point of contact, describe circles to touch the circle first described.

156. **PROBLEM 54.**—*To describe circles with a given radius to touch a given circle in a given point.*

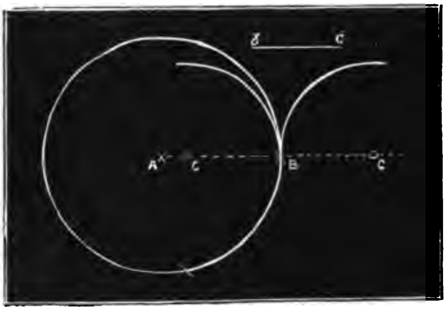

Fig. 117.

Draw a straight line through the centre A, Fig. 117, of the given circle, and the given point, B, on its circumference; on this line set off from the point B, the distance B C equal to the given radius: then the circles described from the centres C with this radius will touch the given circle in the point B.

Reason.—The same as in the last problem.

Exercise.

Describe a circle with a radius of 1·1 inch; take a point on its circumference, and construct circles with a radius of 1 inch, to touch the circle first described in that point.

157. Problem 55.—*To describe a circle which shall pass through a given point and touch a given circle in a given point.*

Join the given point A, Fig. 118, through which the circle is to pass, with given point B, on the circumference of the given circle; join also C, the centre of the given circle, with the given point B on its circumference; through A draw A O, to meet C B produced in O, making the angle B A O equal to the angle A B O; then O will be the centre of the required circle.

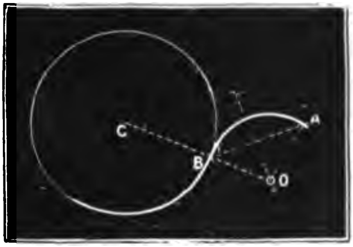

Fig. 118.

Reason.—Since the angles O A B and O B A are equal, the sides O A and O B are equal (Theor. 4), and the circle described from centre O with radius O A will pass through B; and (Theor. 21) will touch the given circle.

Or bisect A B at right angles by a straight line cutting C B produced in O.

Reason.—The circle passing through the points A and B must have its centre on the line bisecting their junction at right angles (Theor. 19); and to touch the circle whose centre is C in the point B, it must (Theor. 21) be on the line C B produced.

If the given point A be on the production of C B, the centre O is the bisection of A B.

Exercises.

(1.) Describe an equilateral triangle of 2 inches side; on the base of this triangle as diameter describe a circle; then describe a second circle to touch the first at one extremity of the base, and pass through the vertex.

(2.) Describe a square with sides of 2 inches; draw its diagonals; with their point of intersection as a centre, and radius of ½ inch, describe a circle; then describe circles to pass through the angular points of the square, and touch the circle first described in the points where it cuts the diagonals.

158. **Problem 56.**—*To describe a circle which shall pass through two given points and touch a given circle.*

Case I.—When the line which bisects at right angles the distance between the two points A and B passes through the centre C of the given circle. In this case the point D, in which the bisecting line cuts the circumference of the given circle, will be the point of contact, and the circle described to touch the given circle in the point D, and pass through one of the given points, will also pass through the other. Hence this case is reduced to the preceding problem.

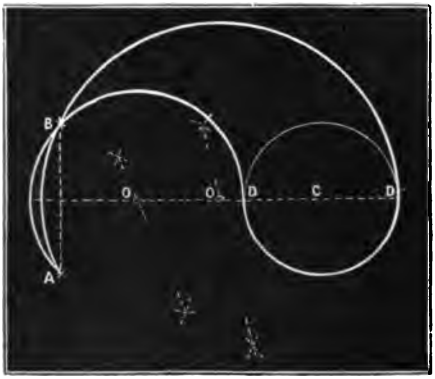

Fig. 119.

Case II.—When the bisecting line O O, Fig. 120, does not pass through the centre of the given circle. From a centre D, on the line O O, at the distance of one of the given points, describe a circle; this circle will pass through the other given point and cut the given circle in two points F and G; join F G; produce A B and G F to meet at H; from H draw H P to touch the given circle in the point P; P shall be the point of contact. Join C P; produce it to meet D O in O; then O is the centre of the required circle, and O A, O B, and O P are radii.

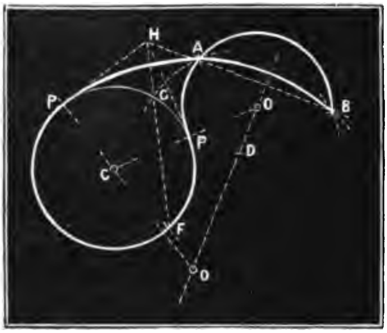

Fig. 120.

Reason.—The rectangle A H, H B is equal to the rectangle G H, H F, which again is equal to the square on H P (Theor. 24);

hence (Theor. 25) the circle through the points A B P touches the straight line H P in the point P. H P then is a common tangent to this circle, and the given circle at the same point P. therefore the two circles must touch one another at this point.

EXERCISES.

(1.) Describe a circle with a radius of 1 inch; from its centre draw two lines inclined at an angle of 37°; on these lines take two points, one on each, at 1⅛ inches and 1¾ inches distance from the centre respectively. Describe a circle to pass through these two points and touch the circle first described.

(2.) Describe a circle with a radius of 1·3 inches; draw a diameter; take two points on the diameter on opposite sides of the centre, and distant from the centre ·5 inch and ·2 inch respectively. Describe a circle to pass through these two points and touch the circle first described.

159. PROBLEM 57.—*With a given radius to describe circles which shall touch a given line and a given circle.*

From C, Fig. 121, the centre of the given circle, draw C B perpendicular to the given line, cutting the circumference of the given circle in the point A; set off from the points A and B, A D and B E, each equal to the given radius pp; with centre C and radius C D, describe a circle, and through E draw a parallel to the given line, cutting this circle in the points O; then the points O are the centres of the required circles.

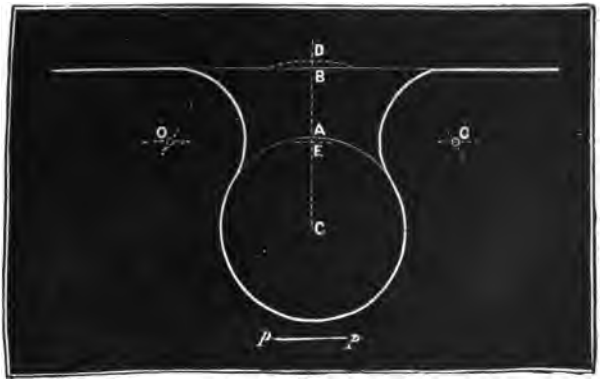

Fig. 121.

Reason.—The centres must be at the distance B E from the given line, and therefore on the line O E O; again, they must be at the distance A D from the circumference of the given circle, and therefore on the arc O D O.

Exercises.

(1.) Describe an equilateral triangle A B C, with sides of 2½ inches; from A as centre, describe a circle whose circumference shall bisect the sides A B, A C; and with a radius of 1 inch describe circles to touch the side B C, and the circle first described.

(2.) Describe a circle with diameter of 1·8 inches; draw a line passing across it at a distance of ·6 inch from the centre; and with radius of ½ inch, describe circles to touch the cutting line and the circle first described.

160. **Problem 58.**—*To describe circles to touch a given line in a given point, and a given circle.*

Method I.—Through the centre C, Fig. 122, of the given circle, draw a perpendicular to the given line, meeting it in the point F, and cutting the circumference in the points D; join the given point A with either point D, and produce A D, if necessary, to meet the circumference in B; then the points B will be the points of contact with the given circle. Draw A O at right angles to the given line A F; join B C and produce it, if necessary, to meet A O in O; then the points O will be the centres of the required circles.

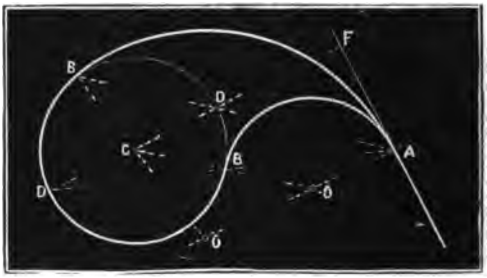

Fig. 122.

Reason.—The angles C B D and C D B are equal to one another (Theor. 4); the angle C B D is either equal to or identical with O B A, and the angle C D B is equal to O A B, since C F is parallel to A O; therefore the angles O A B, O B A, are equal to one another, and O A is equal to O B.

METHOD II.—Through the given point A, Fig. 123, draw A B at right angles to the given line; make A B equal to the radius C D of the given circle; then the centres of the required circles must lie on the line A B, and be equally distant from B and C. Make, therefore, the angle B C O equal to the angle C B O; or bisect B C at right angles, and the intersections O of the bisecting line with A B will be the centres required.

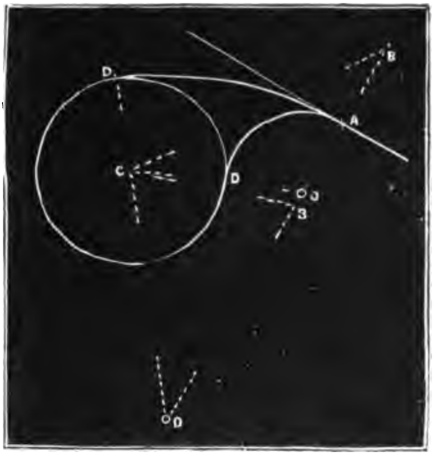

Fig. 123.

Reasons.—Since O B is equal to O C, and A B to C D; O A is equal to O D.

EXERCISES.

(1.) Describe an isosceles triangle, having a base B C 1½ inches long, and sides A B, A C, each 2 inches long; on B C, as diameter, describe a circle. Describe circles to touch the side A B at its middle point, and the circle first described.

(2.) Draw a circle with any radius not less than 1 inch; bisect a radius of this circle, and through the bisecting point draw a chord inclined to the radius at angle of 30°. Describe circles to touch the circle first drawn, and this chord at the point of intersection with the radius.

161. PROBLEM 59.—*To describe circles to touch a given circle in a given point, and a given line.*

METHOD I.—Through the centre C, Fig. 124, of the given circle, draw a perpendicular to the given line, meeting it in the point F, and cutting the circumference in the points D; join the given point A with either point D, and produce A D, if necessary, to meet the given line in B; then B will be the point of contact with the given line. Join A O and produce it both ways; from B draw B O at right angles to B B to meet

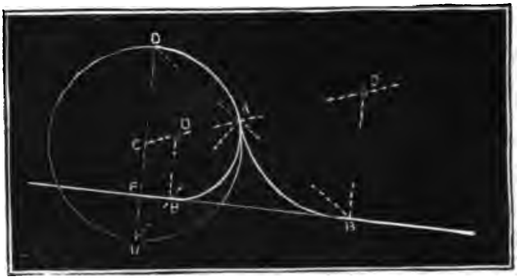

Fig. 124.

A C in O; then the points O will be the centres of the required circles.

Reason.—Exactly like that given for Method I. of the preceding problem.

Method II.—From the centre C, Fig. 125, draw the straight line C A to pass through the given point A; draw A D at right

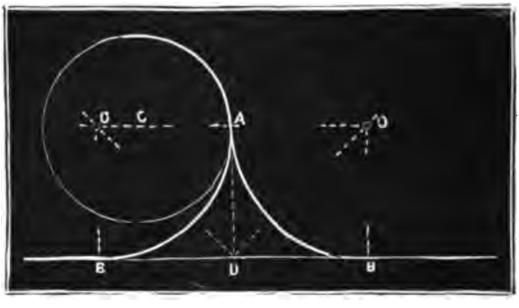

Fig. 125.

angles to C A, to meet the given line in the point D; bisect the angles that A D makes with the given line B B by the straight lines D O intersecting A C in the points O; then O will be the centre of the required circle.

Reason.—The straight line A D touches the given circle at the point A (Theor. 20); the centre of a circle, to touch the lines

A D and D B, the former at the point A, must be on the bisecting line D O, and also on the line A O.

EXERCISES.

(1.) Construct a square A B C D; from centre A, with radius equal to half the side of the square, describe a circle. Describe a second circle to touch this one in the point where it cuts the diagonal of the square, and to touch also the sides B C, C D, of the square.

(2.) Draw a semicircle; divide its arc into three equal parts. Draw circles, each one to touch the arc at a point of section, and the diameter.

162. PROBLEM 60.—*To describe a circle which shall pass through a given point and touch a given line and a given circle.*

Through C, Fig. 126, the centre of the given circle, draw a perpendicular to the given line, meeting it in the point F, and cutting the circumference in the points D and D′; join the given point A with the point F, and with one extremity D of the diameter D D′, and through the other extremity of this diameter, draw D′E, making the angle D D′E equal to the angle D A F, and meeting A D, or A D produced, in E; then the circle described through the two points A E, and touching the given line B F, is the required circle.

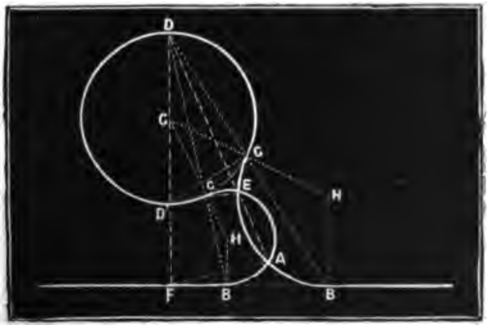

Fig. 126.

Reason.—Let H be the centre of this circle, and B its point of contact with the line B F; join B D, meeting the circle again in the point G, and join H B, H G, G C, and G D′; then the angle D G D′, being in a semicircle, is a right angle; therefore, the triangles D G D′ and D F B are equiangular, and have their sides about equal angles proportionals; therefore, B D is to D F as D D′ to D G; but, by the construction, the triangles D E D′ and D F A are equiangular, and have their sides about equal angles proportionals; therefore, D F is to A D as D E to D D′; therefore, B D is to A D as D E to D G, and consequently the rectangle B D, D G, is equal to the rectangle A D, D E. Hence (Theor. 24.) the circle B A E passes through the point G. H B and H G being, therefore, radii of the circle, the angles H B G and H G B, are equal to one another; but the angles C D G, C G D, are also equal to one another, and, since D F is parallel to H B, the angle C D G is equal to the angle H B G; therefore, also the angle C G D is equal to the angle H G B. Hence the angles H G D, D G C, are equal to the angles B G H, H G D, and these are equal to two right angles, since B G D is a straight line; therefore, H G C is also a straight line (15), and, consequently, the circle B A E G touches the given circle G D D′ in the point G.

EXERCISES.

(1.) Upon a diameter of a circle which measures $1\frac{1}{2}$ inches, describe a square; upon the side of the square, opposite the diameter, describe an equilateral triangle exterior to the square.

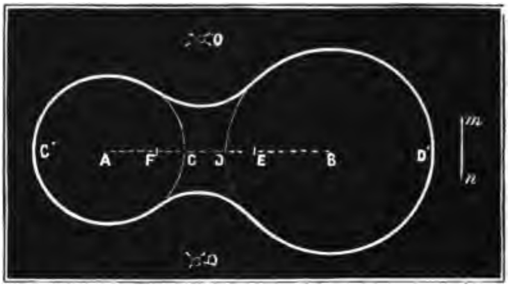

Fig. 127.

Describe circles to pass through an angular point common to the square and triangle, touch the opposite side of the triangle and the given circle.

(2.) An equilateral triangle having been inscribed in a circle of 4 inches diameter, describe circles to pass through the middle point of one of the sides and touch another side and the given circle.

163. PROBLEM 61.—*To describe circles with a given radius to touch two given circles.*

Join the centres A B, Fig. 127, of the two given circles by a straight line cutting the given circles in the points C C′ and D D′; set off from C and D, C E and D F, each equal to the given radius; from centres A and B describe, with radii A E, B F, arcs intersecting in the points O; then the points O will be the centres of the required circles.

Reason.—All circles described with the given radius having their centres on arcs described with radius A E will touch the given circle whose centre is A; and all circles described with the given radius, having their centres on the arcs described with radius B F, will touch the given circle whose centre is B; hence the circles described with the given radius from the several intersections O, will touch both circles.

164. If the given radius be less than half the distance C D there will be no intersection, and no circle can be described with the radius stated to touch both circles.

If the given radius be greater than half the distance C D, and less than the halves both of C D′ and C′ D, there will be two intersections, and consequently two touching circles to both of which the given circles will be external.

If the given radius exceed the half of one of the distances C D′ and C′ D, and fall short of the half of the other, there will be four tangent circles; two to which the given circles will be both external as before, and two to which one of the given circles will be external, while the other will be enveloped by them.

If the given radius exceed the halves of both the distances C D′ and C′ D, but fall short of half the distance C′ D′, there will be six tangent circles; two to which both given circles will be external, and four, to each of which one given circle is external, while the other is enveloped by it.

Lastly, if the given radius exceed the half of C′ D′, there will be eight tangent circles, six of the same nature as in the last case, and two enveloping both given circles.

In all these cases of the problem, the two given circles have been supposed to be entirely external to one another. When they intersect, Fig. 128, and when one falls entirely within the other, other varieties of the problem will present themselves.

EXERCISES.

(1.) Draw three circles with radii of 1 inch to touch each other mutually.

(2.) Describe two circles with the radii of ½ inch and ¾ inch respectively, their centres being 1½ inches apart. Connect them in every possible way by arcs described with a radius of 3 inches.

(3.) Describe two circles with radii of 2 inches, the distance between the centres being 1 inch. Connect them by arcs described with a radius of 1 inch. In how many ways can this be done?

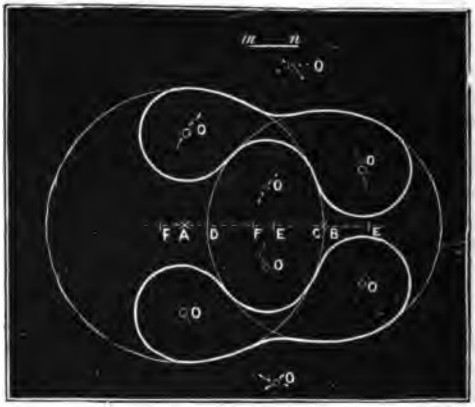

Fig. 128.

(4.) Describe circles with radii of 2 inches and 1 inch respectively, their centres being ½ inch apart. Connect them by arcs of circles with radius of ½ inch.

165. Problem 62.—*To describe circles to touch one given circle in a given point, and another given circle.*

Through C, Fig. 129, the centre of the first given circle, and the given point, A, on its circumference, draw a straight line: set off on this straight line from the point A a distance A D equal to the radius of the second given circle; join B, the centre of this circle, with the points D, and draw B O, making the angle D B O equal to the angle B D C; then the points O, in which the lines B O intersect the line A C, are the centres of the required circles.

Reason.—By the construction O D is made equal to O B, and D A to B E; therefore, O A is also equal to O E.

EXERCISES.

(1.) Describe two circles with radii of ⅓ inch, their centres being 1¼ inches apart; from the centre of one draw a radius inclined at 30° to the line joining the centres. Describe circles to pass through the extremity of this radius, and touch both the circles first described.

(2.) The distance between the centres of two circles is ¼ of an inch; their radii are ⅓ inch and 1 inch respectively; bisect the line joining the centres at right angles, by a straight line which will cut both the circles. Describe circles to pass one of the points in which the bisecting line cuts the smaller circle, and touch both the circles.

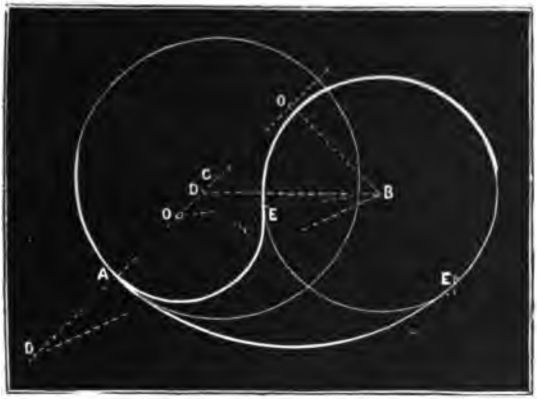

Fig. 129.

(3.) Describe circles to pass through one of the points in which the bisecting line of the preceding problem cuts the larger circle, and touch both circles.

(4.) The centres of two circles are ⅜ inch apart, and their radii are ½ inch and ⅝ inch respectively. Take (1) a point on the smaller circle, and describe circles to pass through it and touch both the given circles. Take (2) a point on the larger circle, and do the same.

166. **PROBLEM 63.**—*To describe circles to pass through a given point, and touch two given equal circles.*

Draw the line O C, Fig. 130, to bisect at right angles the line joining the centres of the two given circles; from the given point A draw A C B perpendicular to O C, and make C B equal to C A; draw circles to pass through the two points A and B, and touch either of the given circles (Prob. 56); these will be the circles required.

Reason.—Every point in the line O C is equidistant from the centres of the two circles, and therefore also equidistant from their circumferences, since their radii are equal. Hence every circle having its centre on O C, and touching one of the circles, will also touch the other: but every circle passing through the two points A and B must have its centre on O C. Hence the circles passing through A B, and touching one circle, will also touch the other.

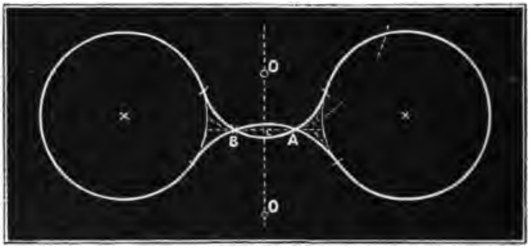

Fig. 130.

EXERCISES.

(1.) The base of a triangle is 2 inches long, and the sides are 1 inch and 1½ inches long respectively; circles are described with radii of ½ inch about the extremities of the base as centres. Describe circles to pass through the vertex and touch both the given circles.

(2.) The base of a triangle is ½ inch long, and the angles at the base are 30° and 45°; with radii of 1 inch circles are described about the extremities of the base as centres. Describe circles to pass through the vertex, and touch both the given circles.

167. PROBLEM 64.—*To describe circles to touch three given straight lines, which are not parallel.*

Bisect the angles contained by the lines; then the intersections of the bisecting lines will be the centres of the required circles. (Fig. 131.)

Reason.—Every point on a line bisecting the angle between two of the given lines is equidistant from these lines; every point on a line bisecting the angle between one of these lines and the third line is equidistant from these two lines; hence the intersection of the two bisecting lines is equidistant from all three of the given lines.

EXERCISES.

(1.) Two parallel lines 1½ inches apart are cut by a third ine; describe circles to touch them all three.

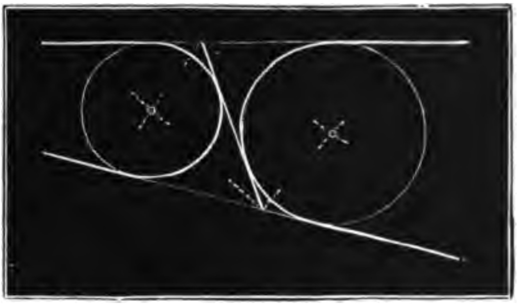

Fig. 131.

(2.) Three lines intersect, the distances between their points of intersection being 2 inches, 2 inches, and 1½ inches; describe circles to touch them all three.

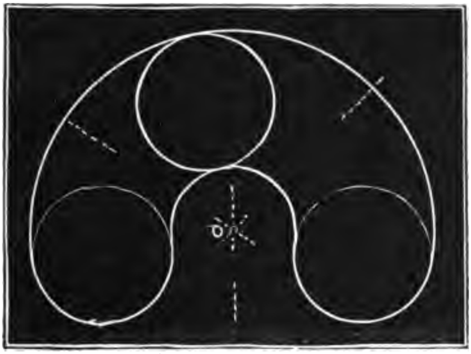

Fig. 132.

168. **PROBLEM 65.**—*To describe circles to touch three equal circles.*

Draw lines bisecting at right angles the lines joining the centres of the given circles: then the point O, Fig. 132, in which the bisecting lines intersect, will be the centre of the required circles. There will be two such circles, the given circles being all exterior to one of them, and being all enveloped by the other.

Reason.—Every point in the line bisecting the distance between the centres of two equal circles is equidistant from the circumferences of these circles; hence the intersection of the bisecting lines is equidistant from the circumferences of all three of the circles.

EXERCISES.

(1.) Circles, each of ½ inch diameter, are described from the middle points of the sides of a triangle as centres, the sides of the triangle being 2 inches, 1·75 inches, and 1·5 inches. Describe circles touching all three of the given circles.

(2.) Circles, each 1 inch in diameter, are described about the angular points of an equilateral triangle with sides 2 inches long. Describe circles touching all three of the given circles.

169. PROBLEM 66.—*To describe circles to touch each of two given lines and a given circle.*

Draw parallels E F, E′ F′, Fig. 133, to the given lines A B, A′ B′, at distances from them equal to the radius of the given circle; find (Prob. 51) centres O of circles to pass through the centre C of the given circle, and touch both the lines E F and E′ F′, in the points F and F′; then the points O will also be the centres of the required circles.

Reason.—O F is perpendicular to both the lines E F and A B; O F is equal to O C, and B F to C P; therefore O B is equal to O P, and so is O B′; and circles described from centres O with radius O P or O B will touch the circle and both the lines A B, A′ B′.

170. There will be four circles answering the required conditions. When the given circle either falls between the given lines, or cuts them both, the given circle and the required circle will touch each other externally in two of the solutions, and in the other two solutions one of the circles will touch the other internally. When the given circle cuts one and only one of the given lines, it will be touched externally in all four solutions.

EXERCISES.

(1.) A right angled isosceles triangle has a base three inches long, and a circle is described with a radius of ¾ inch from a

centre on the base at 1 inch distance from one of its extremities. *Describe circles* to touch the given circle, and the sides of the triangle, or the sides produced.

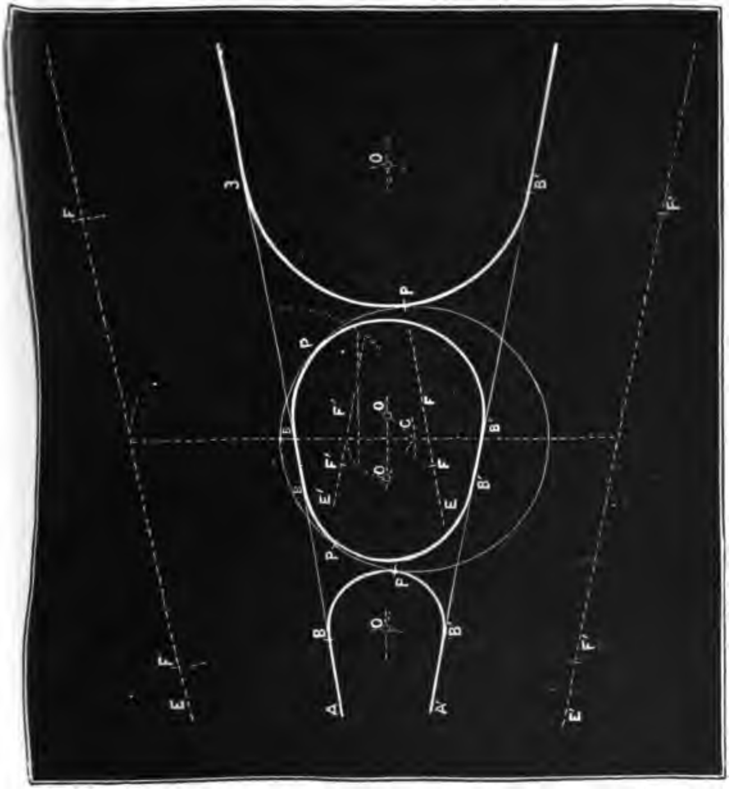

Fig. 133.

(2.) Two lines are inclined to one another at an angle of 30°, from a centre at 3 inches distance from the angular point, and ·7 inch from one of the sides, a circle is drawn with a radius of 1·5 inches. Describe circles to touch this circle and both the lines.

(3.) Two lines are inclined at 60°; from a centre on one of them, at a distance of 1 inch from the angular point, a circle is described with ½ inch radius. Describe circles to touch this circle and both the lines.

171. A great variety of curvilinear forms may be produced by arcs of different circles tangentially connected as in the accompanying diagram, Fig. 134. They may be constructed so as to satisfy various conditions, or to approximate to the form of any curvilinear figure whatever, and the closeness of the approximation may be increased to any extent by increasing the number of centres and diminishing the extents of the several arcs.

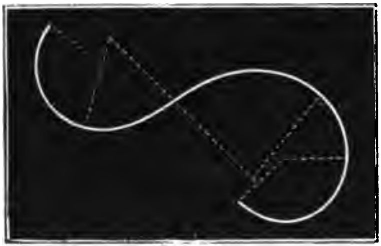

Fig. 134.

172. **Problem** 67.—*To describe an oval of given length and breadth by arcs of circles, having radii of only two different lengths.*

Let C, Fig. 135, be the centre of the oval, A C A its length, and B C B its breadth. The problem may be solved in a variety

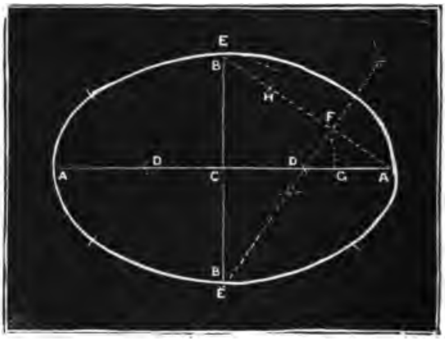

Fig. 135.

of ways, by drawing circles to pass through A at right angles to C A, and other circles tangential to them, to pass through B at right angles to C B. Hence, to make the problem determinate, some other condition may be assumed. Let this condition be that the lines D E, joining the centres D and E of the circles with different radii, shall be at right angles to the lines AB. Join the extremities of the larger and shorter diameters of the oval; on C A set off C G equal to C B; on B A set off B H equal to A G, the difference between C A and C B; bisect A H at right angles by the line E F, cutting C A and C B in the points D and E; then D and E will be centres of the required circles.

Reason.—This will be most clearly given in an algebraical form. Let C A be represented by a, C B by b, and A B by c; then, since A C B is a right angle,

$$c^2=a^2+b^2.$$

The triangles A D F, C E D, B E F, and A C B, are all equiangular, and have their sides about the equal angles proportionals; therefore—

$$\mathrm{AD}=\frac{c}{a}\,\mathrm{AF},$$

$$\mathrm{DE}=\frac{c}{b}\,\mathrm{CD}=\frac{c}{b}\left(a-\mathrm{AD}\right)$$

$$\mathrm{BE}=\frac{c}{b}\,\mathrm{BF}.$$

$$\text{Now, } \mathrm{BF}+\mathrm{AF}=\mathrm{AB}=c,$$

$$\text{and } \mathrm{BF}-\mathrm{AF}=a-b \text{ hyp.};$$

$$\text{therefore } \mathrm{AF}=\frac{c+b-a}{2},$$

$$\text{and } \mathrm{BF}=\frac{c+a-b}{2}.$$

$$\text{Hence, } \mathrm{BE}=\frac{c}{b}\cdot\frac{c+a-b}{2},$$

$$\begin{aligned}
\mathrm{AD}+\mathrm{DE}&=\frac{ac}{b}-\left(\frac{c}{b}-1\right)\mathrm{AD}\\
&=\frac{ac}{b}-\frac{c-b}{b}\cdot\frac{c}{a}\cdot\frac{c+b-a}{2}\\
&=\frac{c}{b}\left(a-\frac{c-b}{a}\;\frac{c+b-a}{2}\right)\\
&=\frac{c}{b}\left(a-\frac{c^2-b^2-a\,(c-b)}{2\,a}\right).\\
&=\frac{c}{b}\left(a-\frac{a-c+b}{2}\right),\text{ since } c^2-b^2=a^2\\
&=\frac{c}{b}\;\frac{c+a-b}{2}\\
&=\mathrm{BE}.
\end{aligned}$$

If then E D be produced to P, making D P = D A, E P = D A + D E = E B, and the circles described from centre D with radius D A, and from centre E with radius E B, will meet at P, and touch another there, since their centres are on the line E P.

EXERCISE.

Describe by circular arcs an oval whose length shall be 3 inches and breadth 2½ inches.

CHAPTER V.

ON ARCS AND SEGMENTS OF CIRCLES.

THEOREMS.

173. **THEOR. 26.**—Upon the same straight line and upon the same side of it, there cannot be two similar segments of circles not coinciding with one another. (Eu. III. 23.)

174. **THEOR. 27.**—In equal circles, equal angles, whether they be at the centres or circumferences, stand upon equal arcs, and *vice versâ*. (Eu. III. 26, 27.)

175. **THEOR. 28.**—In equal circles, equal arcs and equal straight lines mutually subtend each other. (Eu. III. 28, 29.)

PROBLEMS.

176. **PROBLEM 68.**—*A segment or arc of a circle being given, to complete the circle of which it is an arc or segment.*

This is the same problem as Problem 39 for finding the centre of a given circle.

If, however, the circle be so large that the two lines determined to pass through the centre cannot be produced to meet within the limits of the paper, the distance at which these lines will meet or magnitude of the radius may be computed by drawing a parallel to one of the lines to intersect the other and the chord joining their extremities; when we shall have the proportion, section of chord to chord as section of radius to radius.

177. **PROBLEM 69.**—*To describe an arc through three given points without finding the centre of the circle.*

Join the three given points A, B, C, Fig. 136, with each other; from two of the points, A and B, as centres, with radius equal to A B, the distance between them, describe arcs B D, and A E, and produce A C and B C to meet them in the points D and E; take any distance whatever between the points of the compasses, and set it off from D to K and K′, and from E to L and L′, so that the arc A E is diminished and increased by the same amount as the arc B D is increased and diminished; and consequently the sums of the arcs A E and B D, of A L and B K, and of A L′ and B K′ are all equal. Join A K and B L intersecting in P, and A K′ and B L′ intersecting in Q; then P and Q are points in the required arc. Again, by taking other distances and adding them to one of the arcs A E. B D and subtracting them from the other, other points in the arc may in like manner be found; and the curve drawn through all these points will be the arc required.

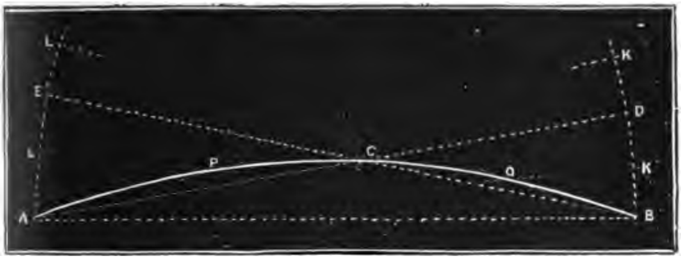

Fig. 133.

Reason.—The arc D K being equal to the arc E L, the angle D A K is equal to the angle E B L (Theor. 27); therefore, adding to each of these equals the angles D A B and L B A, the two angles K A B, L B A, of the triangle P A B, are equal to the two angles D A B, E B A, of the triangle C A B; therefore (Theor. 5) the remaining angle A P B is equal to the remaining angle A C B; and therefore (Theor. 22) P is a point on the arc A C B.

In like manner the point Q is on the same arc, and also other points determined by setting off any other equal distances from D and E on the arcs B D and A E.

This method is of practical utility when the circles to which the arcs belong are so large as to render the mode of striking them from a centre inconvenient.

Exercises.

(1.) The base of a triangle is 3 inches, and the angles at the base are 5° and 7° respectively; describe a circular arc through the angular points of the triangle.

(2.) The span of an arc is 5 inches, and its rise ½ inch; describe the arc.

178. **Problem** 70.—*To continue to any desired extent an arc of a circle already laid down.*

Join A, B, Fig. 137, the extremities of the arc, and draw the chords A C, B C, to a point C upon it; draw C P, making any angle with C A, and B P making the same angle with B A, and let C P and B P meet in P; then P is a point in the prolongation of the arc from the extremity A; and setting off other pairs of equal angles from C A and B A, as many points as necessary in the prolongation may be found, through which the curve may be drawn. In like manner, by setting off pairs of equal angles from C B and A B, the arc may be prolonged from the extremity B.

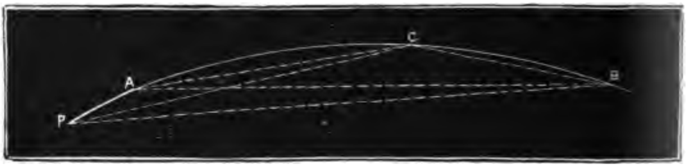

Fig. 137.

Reason.—The angle C P B is, by the construction, made equal to the angle C A B, and as in the preceding problem, P is a point on the arc B C A.

Exercise.

Continue the arc of the last exercise to about one inch from either extremity.

179. **Problem** 71.—*To draw a line touching a given circular arc at a given point without completing the circle or finding its centre.*

Take any convenient distance and set it off twice from the given point P, Fig. 138, to Q and R, and join P R; from P draw P T, making the angle T P Q equal to the angle Q P R; then P T shall be the required tangent.

Reason.—Suppose P V to be a diameter, and Q V to be drawn; then the angles Q R P and Q V P, being in the same segment, are (Theor. 22) equal to one another. Again, P Q being equal to Q R, the angle Q R P is equal to the angle Q P R, and to this T P Q has been made equal; therefore T P Q is equal to Q V P; therefore the angle T P V is equal to the angles Q V P and Q P V; but, since P V is a diameter, the angle P Q V is (Theor. 14) a right angle; therefore (Theor. 5) the angles Q P V and Q V P are equal to a right angle. Hence the angle T P V is a right angle, and T P therefore touches the circle (Theor. 20).

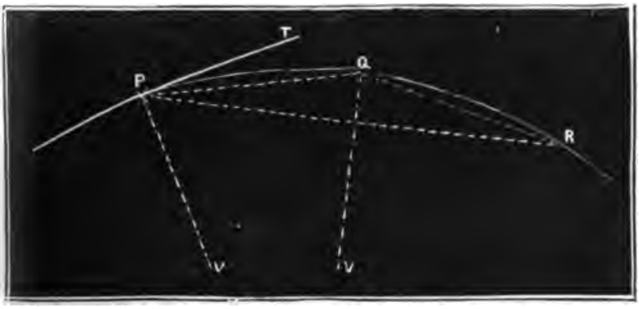

Fig. 138.

Making P Q equal to Q R simplifies the construction; but if P, Q, R be any three points and the angle T P Q be made equal to the angle Q R P, P T will be a tangent to the arc passing through the three points P, Q, R.

Exercises.

(1.) The distance from A to B is 4 inches, from A to C, $2\frac{3}{4}$ inches, and from B to C, $1\frac{1}{2}$ inches; draw a circular arc through the points A B C; continue the arc beyond A to a point P at distance of about 1 inch from A, and drawn through P a tangent to the curve.

(2.) A B is a distance of 6 inches; the angles C A B and C B A measure 3° and 5°; draw a tangent at A to the arc passing through the points A B C.

180. Problem 72.—*To draw a tangent to an arc of a large circle from a point without it.*

From the given point T, Fig. 139, draw T Q R to cut the arc in the points Q and R; find a mean proportional between

T Q and T R (Prob. 33), and set it off from T to P; then T P will be the tangent required.

Reason.—By the construction the rectangle R T, T Q, is equal to the square on T P; therefore (Theor. 25) T P touches the circle.

EXERCISE.

The rise and span of an arc are ·25 inch and 6 inches respectively; draw a tangent from a point at a distance of half an inch, vertically above one extremity of the arc, and measure the length from the given point to the point of contact.—*Ans.* 4·2 inches.

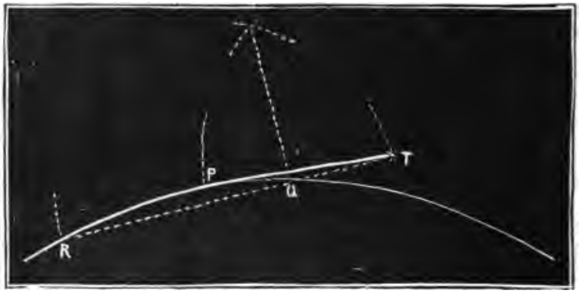

Fig. 139.

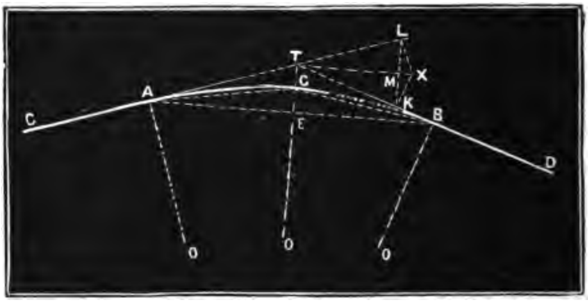

Fig. 140.

181. PROBLEM 73.—*To describe an arc of given radius to touch two given straight lines.*

METHOD I.—Produce the given lines C A, Fig. 140, and D B to meet in the point T; take a distance equal to some convenient aliquot part of the radius, and set it off from T to the point K upon T B, and the point L upon A T produced; from K and L draw K X and L X perpendicular to T K and T L, and let these perpendiculars meet in the point X; take a distance the same multiple of K X or X L that the given radius is of T K or T L, and set it off from T to A and B; then A and B will be the points of contact. Bisect the angles T A B, T B A, by the straight lines A C, B C, meeting in C; then the arc drawn through the points A B C will be the arc required.

Reason.—Join T X, which will bisect the angle K T L. Then if A and B be the points of contact, lines drawn from A and B at right angles to A C and B D, would (Theor. 20) meet at the centre O, and the straight line T O would bisect the angle A T B. Now the angles A T B and B T L are together equal to two right angles; therefore, the halves of these angles, or the angles K T O and K T X, are together equal to a right angle; but, since T K X is a right angle, the angles K T X and K X T are (Theor. 5) also equal to a right angle; therefore the angle B T O is equal to the angle K X T. Also the right angle T K X is equal to the right angle T B O; therefore the triangles K T X and B T O are equiangular, and (Theor. 18) the sides about their equal angles are proportionals, and whatever multiple the radius B O is of T K, the same multiple must T B be of K X.

Again, the angles T A B and T B A being bisected by the lines A C and B C, the angle T A C is made equal to the angle C B A in the alternate segment, and therefore (Theor. 23) C is a point on the arc.

Checks.—If L K be joined, it is bisected at right angles by T X; the point C is on the line T O bisecting the angle A T B, and this line bisects A B at right angles in the point E. Also T E is to E A as T A is to the given radius.

METHOD II.—*By Tangents and Secants.* Measure the angle B T L in degrees and parts of a degree; half this measurement will be the measure of the angle A O T. Now, $\frac{AT}{AO}$ is the trigonometrical tangent of A O T, and $\frac{TO}{AO}$ is its secant; hence T A is the product of the tabular tangent multiplied by the given radius; T O is the product of the tabular secant and the given radius; and T C is this product diminished by the radius. Hence, take from a table of natural tangents and secants the tangent and secant of half the angle B T L; multiply the tabular value of the tangent by the given radius, and the result will be the distance, which, set off from T, will give the points of contact A and B. Again, subtract 1 from the tabular secant; multiply the remainder by the given radius, and the result will be the distance T C.

To find other points on the curve by this method, through A, Fig. 141, draw any line A *e*; measure the angle T A *e*; multiply the value found in the tables for the tangent of this angle by the given radius, and set off the distance thus found from A to *t*; make the angle A *t p* equal to the complement of the angle *t* A *e*; diminish by 1 the tabular value of the secant of *t* A *e*; multiply the remainder by the given radius, and setting off the distance thus found from *t* to *p*, *p* will be a point on the arc. In the same way, any number of points in the arc may be found, and the curve drawn through all these points will be the arc required.

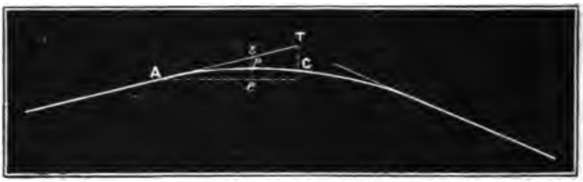

Fig. 141.

EXERCISES.

(1.) Two lines are inclined to one another at an angle of 150°; connect them tangentially by an arc of 10 inches radius. Use Method I.

(2.) Two lines contain an angle of 170°, connect them tangentially by an arc of 60 inches radius. Use Method II.

182. PROBLEM 74.—*To describe an arc to touch a given straight line in a given point, and to pass through another given point, without finding the centre.*

Join the given point A, Fig. 142, on the given line A H, with the other given point B; bisect the angle H A B by the straight line A C; make the angle A B C equal to the angle B A C, and C will be a point in the arc, which can be described through the points A B C by the methods already explained.

Or make the angle A B H equal to the angle B A H; then

B H will be a tangent to the arc at the point B; the product of the tabular cotangent of H A B, multiplied by A H, will be the

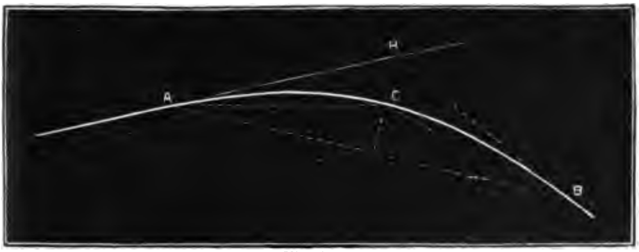

Fig. 142.

radius of the arc; and the arc can be described from these data by the method of tangents and secants.

The tabular cosecant of H A B, multiplied by half of A B, will also give the radius.

EXERCISE.

The angle between two straight lines, A H and A B, is 9°, and the distance from A to B is 3 inches; describe an arc to touch A H at the point A, and to pass through the point B.

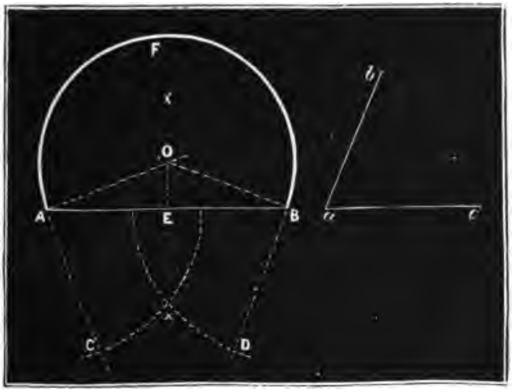

Fig. 143.

183. PROBLEM 75.—*Upon a given straight line to describe a segment of a circle that shall contain an angle equal to a given angle.*

At the extremities A, B, Fig. 143, of the given line, make the angles B A C, A B D, each equal to the given angle *b a c*; draw A O and B O at right angles to A C and B D; then O, the point of intersection of A O and B O, will be the centre of the required segment.

Check.—The line E O, bisecting A B at right angles, will pass through the point O.

Reason.—The angles O A B, O B A, being equal to one another, A O is equal to O B: the circle described with radius O A or O B will (Theor. 20) touch the lines A C and B D; and hence (Theor. 23) the angle B A C or A B D will equal the angle in the alternate segment A F B.

EXERCISES.

(1.) Upon a line 2 inches long, construct a segment to contain an angle of 45°.

(2.) The base of an isosceles triangle measures 1 inch, and the perpendicular from the vertex on the base 1·4 inches; on a line 2 inches long construct a segment to contain an angle equal to one of the angles at the base of the triangle.

184. PROBLEM 76.—*From a given circle to cut off a segment to contain a given angle.*

Draw a straight line C D, Fig. 144, to touch the given circle

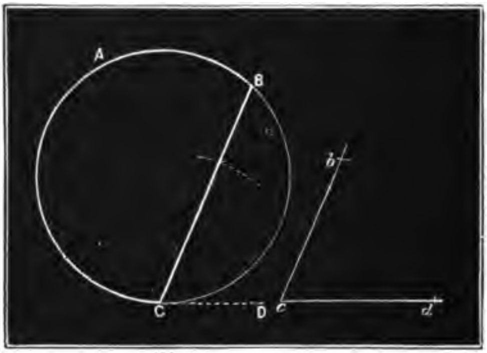

Fig. 144

A B C, in any point C; make the angle D C B equal to the given angle *b c d*; then this line will cut off the required segment A B C.

Reason.—The angle B C D is (Theor. 23) equal to the angle in the alternate segment A B C.

EXERCISES.

(1.) From a circle 2 inches in diameter, cut off a segment to contain an angle of 54°.

(2.) The sides of a triangle are 1 inch, 2 inches, and 3 inches; from a circle of $1\frac{1}{2}$ inches diameter cut off a segment to contain an angle equal to the greatest angle of the triangle.

185. PROBLEM 77.—*Given the base, the vertical angle, and the perpendicular in a plane triangle, to construct it.*

Upon the given base A B, Fig. 145, describe (Prob. 75) a segment to contain an angle equal to the given angle *a c b*; draw a parallel to A B, at a distance from it equal to the given perpendicular *d e*, to meet the circumference in the points C and D; then either C A B or D A B is the triangle required.

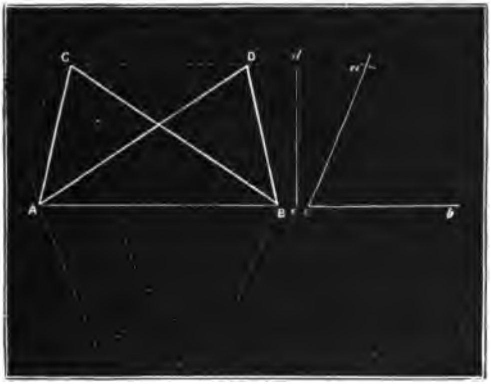

Fig. 145.

Reason.—Every angle in the segment A C D B being equal to the given vertical angle, both A C B and A D B are equal to this angle, and the perpendicular is the distance between C D and A B.

If C D touch the circle there will be only one triangle, which can be constructed upon the base A B, with the given altitude and vertical angle.

If C D pass entirely without the circle, no triangle can be described on A B with the given latitude and vertical angle.

EXERCISE.

Construct a triangle having a vertical angle of 30°, a base of 1¼ inches, and an altitude of 1 inch.

186. PROBLEM 78.—*The vertical angle, and the sums of the sides containing it, being given, to construct the triangle upon a base given both in magnitude and position.*[*]

Upon the given base A B, Fig. 146, describe a segment A D B, to contain an angle equal to half the given angle *a c b*; from A, as centre, with distance equal to *a d*, the given sum of the two sides, strike an arc cutting A D B in the points D, and make the angle D B C equal to the angle B D C; then will either of the triangles C B D be the required triangle.

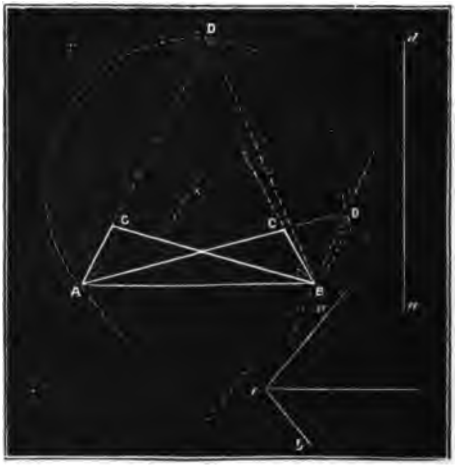

Fig. 146.

Reason.—The angles C D B and C B D being equal to one another, C B is equal to C D: therefore, A C and C B together are equal to A D, or to the given sum. Again, A C B being equal (Theor. 5) to the two equal angles C B D and C D B, is double of one of them, C D B, and is therefore equal to the given vertical angle.

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[*] If the base were given in magnitude only, the problem would be identical with Problem 22.

If the given length A D be equal to the diameter of the circle A D B, there will only be one triangle answering the given conditions. If A D be greater than the diameter of the circle A D B, no triangle can be described to answer the given conditions.

EXERCISE.

Draw a line 1½ inches long, and upon it describe a triangle such that the vertical angle shall be 60°, and the sides containing it shall together measure 2 inches.

187. PROBLEM 79.—*The vertical angle, and the difference of the two sides containing it, being given, to construct the triangle on a base given both in magnitude and position.*[*]

Draw A E at right angles to the given base A B, Fig. 147, and make the angle E A F equal to half the given angle *a c b*; upon A B describe a segment A D B to contain an angle equal to the angle B A F; from centre A with distance A D, equal to the given difference of the sides, strike an arc cutting A D B, the circumference of the segment, in the point D; join A D, D B, and, producing A D, make the angle D B C equal to the angle B D C; then shall A B C be the triangle required.

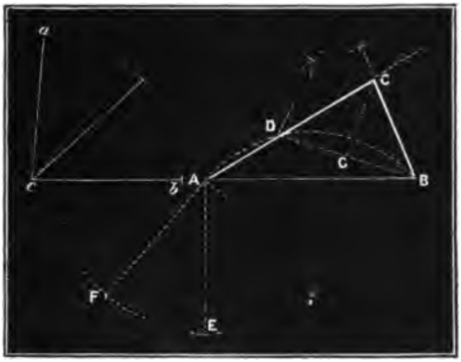

Fig. 147.

Reason.—Draw C G to bisect the angle D C B; then will C G be at right angles to B D. The angle A D B is equal to the two angles D G C and D C G (Theor. 5), and by the construction it is also equal to B A F; therefore, B A F is equal to the two angles D G C and D C G. But the right angle D G C is equal to the right angle B A E; therefore, the angle D C G is equal to the angle E A F, or half the given angle *a c b*, and therefore the entire vertical angle A C B is equal to the given angle. Again, C D is equal to C B, and therefore the excess of A C above C B is equal to A D, the given difference of the sides.

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[*] If the base were given in magnitude only, the problem would be identical with Problem 23.

EXERCISE.

Draw a base 2 inches long, and upon it describe a triangle such that the vertical angle shall be 45°, and the difference of the sides containing it shall measure 1 inch.

188. PROBLEM 80.—*The base, the vertical angle, and the ratio of the two sides being given, to construct the triangle.*

Divide the given base, A B, in the point D, so that A D may have to D B the given ratio; upon A B describe a circle A C B E, so that the angle in the segment A C B may be equal to the given angle *a c b*; bisect the arc A E B in the point E; join E D and produce it to C; join A C, C B; then A B C shall be the required triangle.

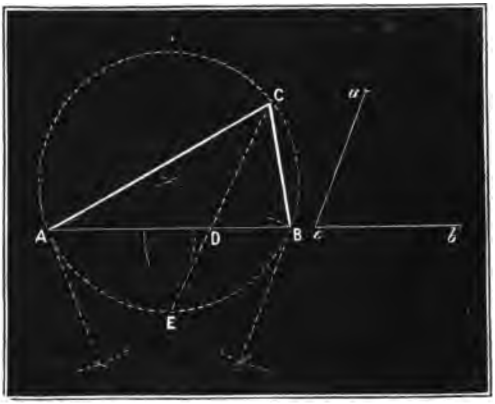

Fig. 148.

Reason.—The angle A C B in the segment A C B is equal to the given vertical angle. Also, the arcs A E and E B being equal, the angles A C E and E C B are also equal (Theor. 27), and the angle A C B is bisected by the straight line A D; therefore (Eu. VI. 3) A C has to C B the same ratio as A D to D B, which was made equal to the given ratio.

EXERCISE.

Construct a triangle of which the base shall be 2½ inches, the vertical angle 50°, and the sides shall have the ratio of 2 to 1.

CHAPTER VI.

OF INSCRIBED AND CIRCUMSCRIBED FIGURES.

189. **PROBLEM 81.**—*In a given circle to place straight lines equal and parallel to a given straight line not greater than the diameter of the circle.*

Bisect the given line A B, Fig. 149, in the point D, and join this point with C the centre of the given circle; through A and B draw A E and B F, parallel to D C, to meet the diameter parallel to A B, in the points E and F; at E and F draw E G and F H, perpendicular to the diameter E F, to meet the circumference in G and H; join G H; then G H is equal and parallel to A B.

Reason.—The figures E D, D F, E B, are parallelograms; therefore, E F is equal to A B, and E C, C B, are equal to A D, D B, respectively; therefore E C is equal to C F; therefore, E G is equal to F H (Eu. III. 14). Hence, since E G and F H are equal and (Theor. 9) parallel, G H is (Theor. 10) equal and parallel to E F, that is, to A B.

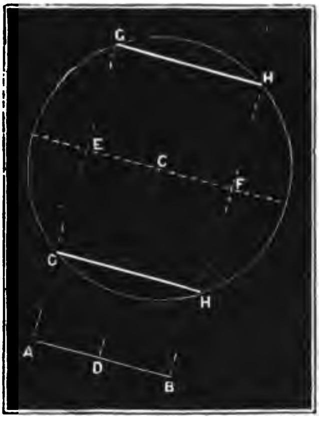

Fig. 149.

EXERCISE.

Construct a triangle with sides of ½ inch, 1½ inches, and 1¾ inches; describe a circle round one of its angular points as centre with a radius of 2 inches. Place in the circle lines equal and parallel to the sides of the triangle.

190. **Problem** 82.—*To inscribe squares in a given triangle.*

From A, Fig. 150, one of the angular points of the triangle, draw A E parallel, and A D perpendicular to, the opposite side, B C, of the triangle; make A E equal to A D, and join B E, cutting A C in F; through F draw F G parallel to B C, and F H parallel to A D; through G draw G K parallel to A D; then G K H F is a square.

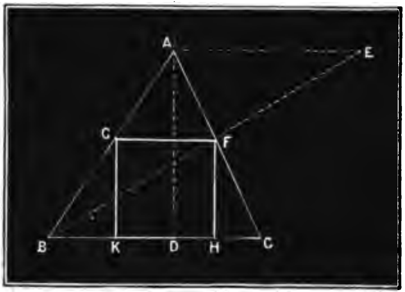

Fig. 150.

Reason.—The triangles G B K and A B D are equiangular, and so also are the triangles B G F and B A E; therefore, (Theor. 18)

G K : A D : : B G : B A : : G F : A E;

but A D is equal to A E; therefore, G K is equal G F, and the parallelogram G H is equilateral. Again, A D being perpendicular to B C, F H and G K parallel to A D are also perpendicular to B C, and the parallelogram is rectangular; therefore, it is a square.

In like manner two other squares may be described in the triangle, having their bases on the sides A B, A C, respectively.

Exercises.

(1.) The base of a triangle is 2 inches long, and the angles at the base are 35° and 65° respectively. Inscribe squares in the triangle.

(2.) An equilateral triangle has sides of $1\frac{1}{4}$ inches. Inscribe squares in the triangle.

(3.) Two sides of a triangle are each $1\frac{3}{4}$ inches long, and include an angle of 50°. Inscribe squares in the triangle.

191. **Problem** 83.—*To inscribe an equilateral triangle in a square,* (1) *when the vertex of the triangle is on an angular point of the square;* (2) *when the vertex is on the bisecting point of a side of the square.*

(1.) From the angular point A, Fig. 151, draw A C and A D, making with the diagonal A B, the angles B A C, B A D, each equal to 30°, or one-third of a right angle, and join C D; then A C D will be the required triangle.

Reason.—In the triangles A E C, A F D, the angles E A C and F A D are equal by construction, the right angles at E and F are equal, and the side A E is equal to the side A F; therefore, the triangles are equal in all respects, and A C is equal to A D. Hence the angles A C D and A D C are equal to one another; and, since C A D is two-thirds of a right angle, A D C and A C D are also each two-thirds of a right angle, and the triangle A C D is equiangular; it is therefore (Theor. 4) equilateral.

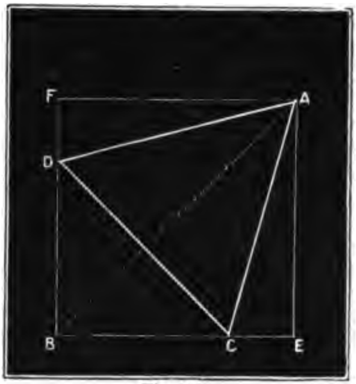

Fig. 151.

(2.) Bisect A B, Fig. 152, a side of the square in the point C, and from C draw C D, C E, making the angles A C D, B C E, each equal to 60° or two-thirds of a right angle, and join D E; then C D E will be the triangle required.

Reason.—A C D and B C E being each two-thirds of a right angle, D C E is also two-thirds of a right angle; also, as in the preceding case, the angles C D E and C E D are equal to one another, and each, therefore, to two-thirds of a right angle. Hence, as before, the triangle C D E is equilateral.

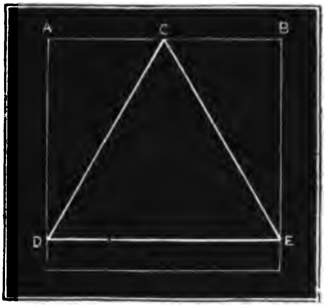

Fig. 152.

Exercise.

Describe a square on a line 1·6 inches long. Inscribe in it equilateral triangles with their vertices on an angular point, and on the bisection of a side.

192. Problem 84.—*To inscribe a regular hexagon in a given equilateral triangle.*

Bisect A B C, A C B, Fig. 153, any two of the angles of the triangle, by straight lines intersecting at D; through D draw E H, F K, L G, parallel respectively to the sides A B, A C, B C, of the triangle; join F G, H K, L E; then E F G H K L is the required regular hexagon.

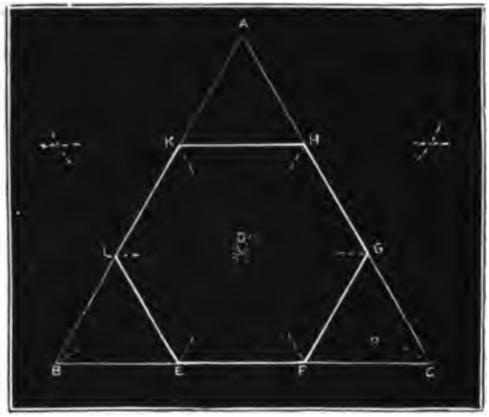

Fig. 153.

Reason.—By the construction the side B C is trisected (Prob. 36), and the figure B D is a parallelogram; therefore, E F and L D are each equal to B E, and therefore to one another. Hence E F and L D being both equal and parallel, L F is also a parallelogram (Theor. 10) and L E equal to D F. The triangle D L E has therefore its sides respectively equal to the sides of the triangle D E F, and is therefore equilateral. Hence L E is equal to E F. In like manner each of the sides F G, G H, H K, K L, is equal to E F or L E, and the hexagon is equilateral. Again, each of the angles of the hexagon is equal to two angles of equilateral triangles, and the hexagon is equiangular.

EXERCISE.

Construct an equilateral triangle on a base of 3 inches, and inscribe in it a regular hexagon.

193. **Problem** 85.—*To inscribe a regular octagon in a given square.*

On A B, Fig. 154, describe a semicircle A D B; bisect A B at right angles by C D cutting the semicircle in the point D; from centres A and B, with radius A D or D B, describe arcs cutting A B in the points E and F, then E F will be a side of the required octagon; and setting off on the other sides of the square the distance A E or B F from its angular points, the angular points of the octagon will be determined.

It is to be noted that the point D is also the intersection of the diagonals of the square.

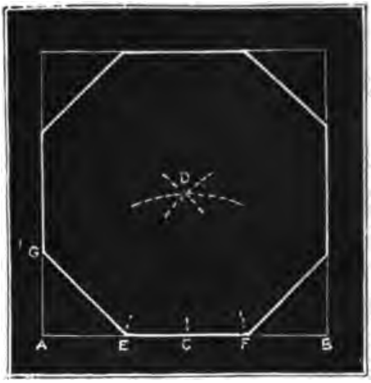

Fig. 154.

Reason.—Making A G equal to A E, and joining E G, the triangles G A E and A D B are equiangular, and therefore (Theor 18)—

A B : A D or A F : : E G : A E.

Now by construction—

A C : A F : : A F : A B;
∴ A C : C F : : A F : F B or A E;
∴ since A B is equal to twice A C, and E F to twice C F;
A B : E F : : A F : A E;
and ∴ A B : : A F : : E F : A E.

But we have seen that—

A B : A F : : E G : A E;
therefore, E G is equal to E. F.

In like manner the other sides of the figure are equal to E G or E F, and the octagon is equilateral, and equiangular.

194. **Problem** 86.—*In a given circle to inscribe a triangle having given angles.*

Draw a straight line D A E, Fig. 155, touching the circle; from the point of contact A draw A B, A C, making the angles

D A B, E A C equal to two of the given angles; join B C, then A B C is the required triangle.

Reason.—The angle A B C is (Theor. 23) equal to the angle E A C, one of the given angles; the angle A C B is in like manner equal to D A B, another of the given angles; and, therefore, B A C is equal to the third angle.

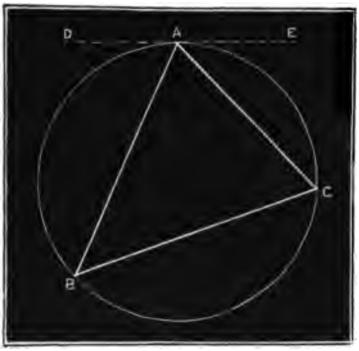

Fig. 155.

EXERCISES.

(1.) Construct a triangle whose sides are 1·2 inches, 1·5 inches, and 1·7 inches, and place a triangle equiangular to it in a circle whose diameter is 1¼ inches.

(2.) Inscribe an equilateral triangle in a circle with a diameter of 2 inches.

(3.) Inscribe in a circle whose radius is ·9 inch an isosceles triangle whose vertical angle is 40°.

Note.—An equilateral or isosceles triangle may also be inscribed in a circle by setting off half the vertical angle from the extremity of a diameter on each of it. (Fig. 156.)

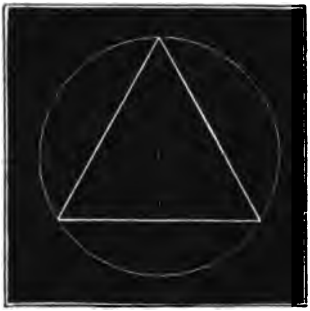

Fig. 156.

195. PROBLEM 87.—*About a given circle to describe a triangle having angles equal to given angles.*

Draw A B, Fig. 157, any radius of the circle; from A draw A C, A D, making the angles B A C, B A D equal to two of the given angles; produce C A, D A, to E and F; through the points B, E, F, draw H K, K G, G H, at right angles to A B, A E, A F respectively; then G H K will be the required triangle.

Reason.—Since the four angles of the quadrilateral A B K E are (Theor. 6) equal to four right angles, and that A B K and A E K are right angles; therefore B A E and B K E are equal to two right angles; but B A E and B A C are also (15) equal to two right angles; therefore B K E is equal to B A C, one of the given angles. In like manner B H F is equal to B A D, another

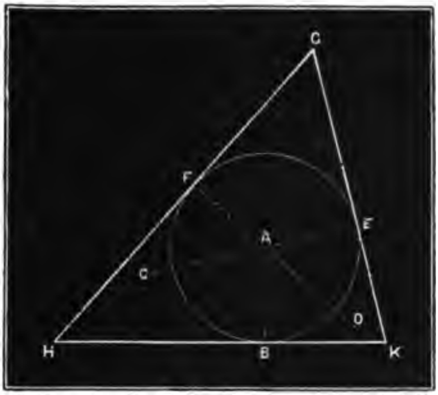

Fig. 157.

of the given angles; and therefore H G K is equal to the third angle.

EXERCISES.

(1.) About a circle of ·6 inch radius describe a triangle having angles of 50°, 60°, and 70°.

(2.) About a circle of 2 inches diameter describe an equilateral triangle.

(3.) About a circle of 1·4 inches diameter describe an isosceles triangle, each of the angles at the base being equal to 65°.

196. PROBLEM 88.—*To inscribe a circle in a given triangle.*

This problem is a part of the more general problem already solved (Prob. 64), to describe circles tangential to three given lines.

197. PROBLEM 89.—*To describe a circle about a given triangle.*

This problem is identical with problem 40, to describe a circle through three given points.

EXERCISE.

Construct a triangle whose two sides are 1·2 inches and 2·1 inches and perpendicular from the vertex on the base 1 inch. Describe a circle about the triangle and measure the length of its diameter. *Ans.* 2·52 inches.

198. Problem 90.—*To inscribe a square in a given circle.*

Draw two diameters A C and B D, Fig. 158, at right angles to one another; join A B, B C, C D, D A; A B C D shall be the square required.

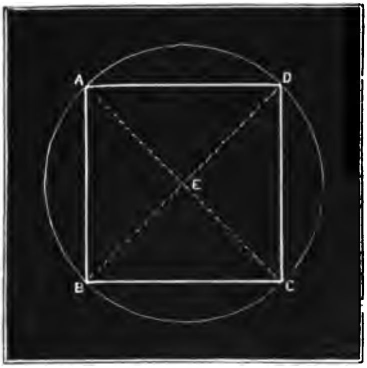

Fig. 158.

Reason.—The two sides A E, E B, being equal to the two sides C E, E B, each to each, and the right angle A E B to the right angle C E B, the base A B is equal to the base B C. In like manner A D, D C, are each of them equal to A B or B C, and the quadrilateral A B C D is equilateral. Again, each of its angles being the angle in a semicircle is (Theor. 14) a right angle. The quadrilateral, then, being both equilateral and rectangular, is a square.

Exercise.

About an equilateral triangle with sides of 2 inches describe a circle. Inscribe a square in the circle and measure its side. *Ans.* 1·63 inches.

199. Problem 91.—*To describe a square about a given circle.*

Draw two diameters, A C and B D, Fig. 159, at right angles to one another; through the points A B C D draw F K, F G, G H, H K, at right angles to A C and B D; then F G H K shall be the required square.

Reason.—F K, F G, G H, H K, being at right angles to diameters, touch the circle (Theor. 20); therefore the quadrilateral F G H K is described about the circle. The angles at A and E being right angles, F K is (Theor. 9) parallel to B D. In like manner G H is parallel to B D, and F G and H K parallel to A C; therefore F D, D G, G A and A H are parallelograms; therefore F K, G H are each equal to B D, and F G, H K, each equal to A C; and A C being equal to B D, the quadrilateral is equilateral. Again F E being a parallelogram, and A E B a right angle, the angle at F is (Theor. 11) also a right angle, and similarly the angles at G, H, K, are right angles; therefore the figure is rectangular.

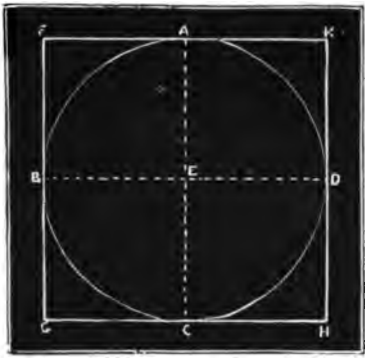

Fig. 159.

Exercises.

(1.) Describe a square about a circle of 2½ inches diameter.

(2.) Describe a circle about a triangle whose sides are 2 inches, 2 inches, and 1 inch. Describe a square about this circle. What is the length of its side? — *Ans.* 2·1 inches.

200. Problem 92.—*To inscribe a circle in a given square.*

Draw A C, B D, Fig. 160, the diagonals of the square, intersecting in the point E; from E draw E F perpendicular to A D; then E shall be the centre and E F a radius of the required circle.

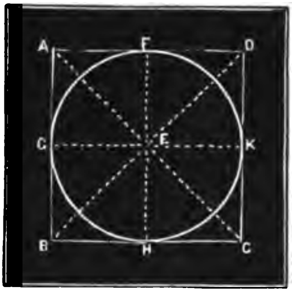

Fig. 160.

Reason.—From E draw E G, E H, E K, perpendicular to A B, B C, C D respectively. The sides B A, A C, of the triangle B A C are equal to the sides D A, A C, of the triangle D A C, and the base B C is also equal to the base C D; therefore the angle B A C is equal to the angle D A C (Theor. 2); also the right angle A G E is equal to the right angle A F E, ad the side A E is common to the two triangles E A G, E A F; therefore (Theor. 3) E F is equal to E G. In like manner E H, E K, are each equal to E F or E G. Hence the circle described from centre E with radius E F will pass through the points G, H, and K, and (Theor. 20) touch the sides A B, B C, C D, D A, since the angles at F, G, H, K, are right angles

EXERCISES.

(1.) Inscribe a circle in a square having sides 2¼ inches long

(2.) Describe an equilateral triangle with sides of 2¾ inches; inscribe a square in the triangle. Inscribe a circle in the square. Measure the diameter of the circle.—*Ans.* 1·28 inches.

201. PROBLEM 93.—*To describe a circle about a given square.*

Draw A C, B D, Fig. 161, the diagonals of the square, intersecting in E; then E will be the centre of required circle, and the diagonals will be diameters.

Reason.—It has been shown in the preceding problem that the angles B A C and D A C, are equal, so that the angle B A D is bisected by the diagonal A C; and in like manner the other angles of the square are each bisected by a diagonal. Again, the angles B A D and A D C being equal to one another, their halves, the angles E A D and E D A, are equal to one another; therefore (Theor. 4) E A is equal to E D. In like manner, E B, E C, are each equal to E A or E D; and the circle described with centre E, and radius equal to half the diagonal, will pass through the angular points and be described about the square.

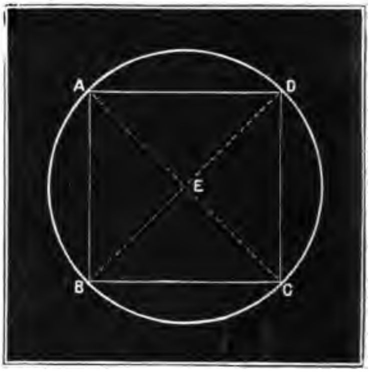

Fig. 161.

EXERCISE.

Describe a circle with a diameter of 1½ inches; about this circle describe a square. Describe a circle about the square, and measure its diameter—*Ans.* 2·12 inches.

202.—PROBLEM 94.—*To inscribe a regular decagon in a given circle.*

Draw two diameters, A B and D E, Fig. 162, at right angles to one another; bisect A C in F; from centre F with radius

F D, describe an arc cutting A B in G, then C G will be a side of the required decagon, which will therefore be described by placing chords equal to C G all round the circumference.

Reason.—Draw B H, one of the chords, equal to C G, and join C H; then, since (Eu. II. 11) the rectangle C B, B G, is equal to the square on C G, and B H is equal to C G, the triangle C B H (Prob. 26) has each of the angles at the base double of the angle B C H, at the vertex; therefore, the angle B C H is a fifth part of two right angles, or a tenth part of four right angles. Hence ten chords, each equal to B H, will exactly go round the circumference, and form a regular decagon.

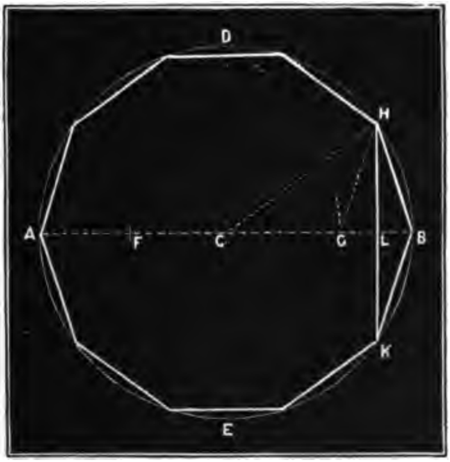

Fig. 62.

EXERCISE.

Inscribe a regular decagon in a circle of 3 inches diameter.

203. PROBLEM 95.—*To inscribe a regular pentagon in a given circle.*

METHOD I.—Find the side of a regular decagon inscribed in the circle by the construction explained in the preceding problem; place in the circle two chords, B H, B K, each equal to the side thus found; join H K; then H K will be a side of the required pentagon, which will therefore be described by placing chords equal to H K all round the circumference.

Method II.—The same construction being made as in the preceding problem, D G will be equal to a side of the pentagon, which will therefore be described by placing chords equal to D G all round the circumference.

Reason.—Join H G, which will be equal to H B or C G (Eu. IV. 10), and G L will be equal to L B, and H L to L K; therefore HK^2+GB^2 is equal to $4\,HL^2+4\,LB^2$, and, therefore, to $4\,HB^2$, or $4\,CG^2$. Now CG^2 is equal to $CB \cdot BG$, and, therefore, to $CG \cdot GB+GB^2$; therefore, $4\,CG^2$ is equal to $2\,CG^2+2\,CG \cdot GB+2\,GB^2$, and, therefore, to $CB^2+CG^2+GB^2$. But, HK^2+GB^2 has also been shown to be equal to $4\,CG^2$; therefore, HK^2+GB^2 is equal to $CB^2+CG^2+GB^2$, and, therefore, HK^2 alone is equal to CB^2+CG^2, or to CD^2+CG^2, that is, to DG^2; therefore, H K, the side of the pentagon, is equal to D G.

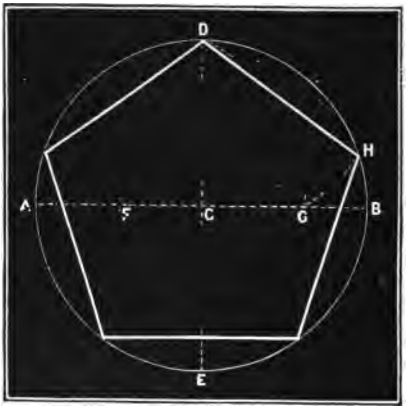

Fig. 163.

Hence the simplest mode of describing the pentagon is shown in the accompanying figure (Fig. 163). A F equals F C; F G equals F D; D H equals D G.

The decagon may also be inscribed by bisecting the arcs subtended by the sides of the pentagon.

EXERCISES.

(1.) Inscribe a regular pentagon in a circle of 2·3 inches diameter, and give the measurements of a side and of a diagonal.—*Ans.* 1·35 inches; 2·19 inches.

(2.) The base of an isosceles right-angled triangle is 3 inches; inscribe a circle in the triangle. Inscribe a regular pentagon in the circle. Give the measurements of a side and of a diagonal.—*Ans.* ·83 inches; 1·32 inches.

204. **PROBLEM** 96.—*To inscribe a regular hexagon in a circle.*

METHOD I.—Draw a diameter A G D, Fig. 164, G being the centre of the circle; from centre D, with radius D G, strike arcs cutting the circle in the points C and E; join C G, E G, and produce them to meet the circumference at F and B; join A B, B C, C D, D E, E F, F A; then A B C D E F shall be the required hexagon. The points B and F will also be found by striking arcs from centre A with radius A G.

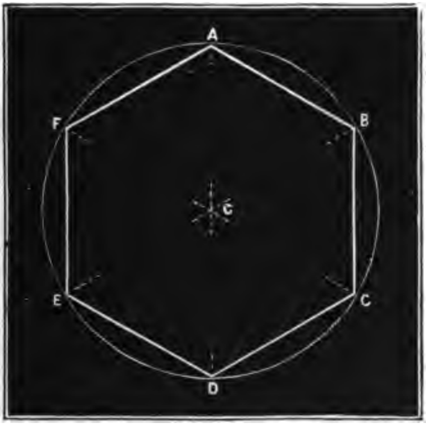

Fig. 164

Reason.—The triangles G C D and G D E are equilateral by the construction, hence each of the angles C G D, D G E, is a third of two right angles; therefore, also (15) the angle E G F is a third of two right angles; therefore, the three angles C G D, D G E, E G F, are equal to each other; and to these are respectively equal (Theor. 7) the vertical opposite angles F G A, A G B, G B C; hence the six angles are equal to each other, and consequently the six chords connecting their extremities are also equal.

Method II.—Set chords equal to the radius all round the circumference.

Reason.—C D is equal to C G by the construction just given.

Exercises.

(1.) Inscribe a hexagon in a circle whose diameter is 2·1 inches.

(2.) In an equilateral triangle of 3·2 inches side inscribe a circle. Inscribe a regular hexagon in the circle. Measure the side of the hexagon.—*Ans.* ·92 inches.

205. Problem 97.—*To inscribe a regular dodecagon in a given circle.*

Draw two diameters A D, B E, Fig. 165, at right angles to one another; with same radius as that of the given circle strike arcs from A, B, D, E, as centres, to cut the circumference; then the circumference will be divided into twelve equal arcs, and their chords will form the required dodecagon.

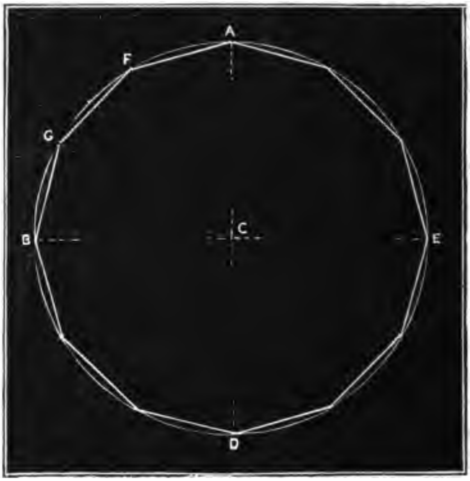

Fig. 165.

Reason.—A C G, being the angle of an equilateral triangle, is two thirds of a right angle, and A C B is a right angle; therefore, B C G is one-third of a right angle or one-twelfth of four right angles. In like manner A C F is one-third of a right angle, and therefore also F C G is one-third of a right angle, or one-twelfth of four right angles. In the same manner each of the right angles B C D, D C E, E C A, has been trisected, and the whole four right angles consequently divided into twelve equal angles.

EXERCISE.

Inscribe a dodecagon in a circle of 3 inches diameter, and measure its side.—*Ans.* ·78 inches.

206. PROBLEM 98.—*To inscribe a regular quindecagon in a given circle.*

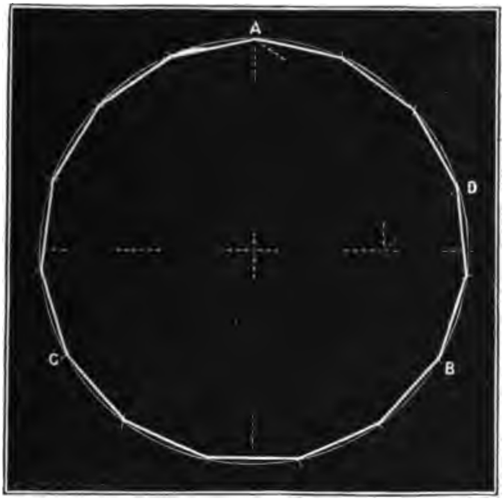

Fig. 166.

Mark off (Prob. 86) on the circumference the angular points A, B, C, Fig. 166, of an equilateral triangle inscribed in the given circle; find (Prob. 95) the side A D of a regular pentagon inscribed in the circle, and step with this distance all round the circumference from each of the points A, B, C; then will there be fifteen points marked at equal distances, and the fifteen chords joining them will form the required quindecagon.

Reason.—The circumference has to be divided into fifteen equal parts; it is divided into three at A, B, C; hence the arcs A B, B C, C A, contain each five of the required parts. Again, the arc A D being one-fifth of the circumference, contains three of the required parts, and hence, by stepping round the circumference from A, with the distance A D, five of the points of division will be determined; and in like manner, five more of the points will be determined by stepping from B and the remaining five by stepping from C.

EXERCISE.

Inscribe a regular quindecagon in a circle of 4 inches diameter, and measure a side.—*Ans.* ·83 inches.

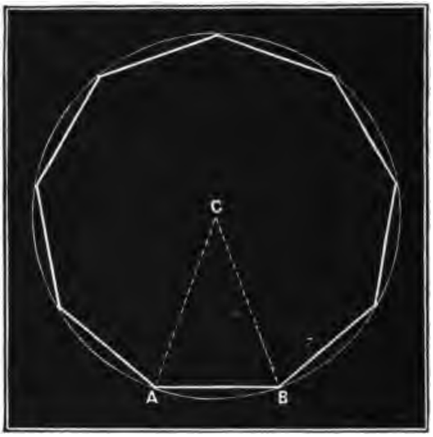

Fig. 167.

207. PROBLEM 99.—*To inscribe a regular polygon of any given number of sides in a given circle.*

METHOD I.—Draw a radius, C A, Fig. 167; divide 360° by the given number of sides; make the angle A C B equal to the angle thus found; then the chord A B will be a side of the polygon, which will be described by placing chords equal to A B all round the circumference.

Thus, to describe a regular nonagon in the circle; make the angle A C B equal to $\frac{360}{9}^{\circ}$, or 40°.

Reason.—If n be the number of sides, the angle A C B will, by the construction, be the nth part of four right angles, and the arc A B the nth part of the circumference.

METHOD II.—Divide 180° by the given number of sides; look for the sine of the angle thus found in a table of natural sines; multiply the diameter of the given circle by this tabular number; with the distance thus found step round the circumference. Thus, to inscribe a regular heptagon in a circle with a diameter of 3 inches: $\frac{180}{7}^\circ = 25\frac{5}{7}^\circ$; the natural sine of $25\frac{5}{7}^\circ$, or 25° 43′, will be found from the tables to be ·434 nearly; and multiplying this by 3, we obtain 1·3 for the side of the required heptagon. (Fig. 168.)

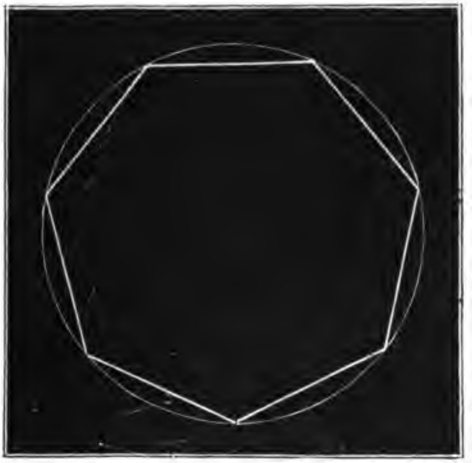

Fig. 168.

Reason.—The chord of an arc is twice the sine of half the arc (*see* Trigonometry), hence the chord of $\frac{360}{n}^\circ$ is equal to twice the sine of $\frac{180}{n}^\circ$. Now the sine of an arc is found by multiplying the tabulated sine by the radius of the circle; hence, twice the sine of an arc, or the chord of twice the arc, is found by multiplying the tabulated sine by the diameter.

EXERCISES.

(1.) Inscribe a regular heptagon in a circle with a radius of 1 inch.

(2.) Inscribe a regular nonagon in a circle with a diameter of 3 inches.

(3.) Inscribe a regular polygon of eleven sides, in a circle with a diameter of 4 inches.

208. Problem 100.—*To describe a regular polygon of any given number of sides about a given circle.*

Determine, by one of the preceding problems, the angular points of a regular polygon of the same number of sides inscribed in the circle; through the points thus found draw tangents to the circle, and the polygon required will be described.

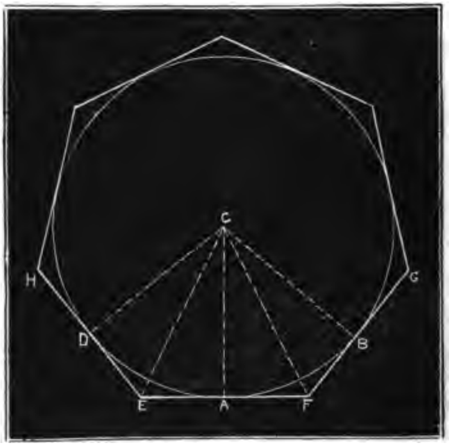

Fig. 169.

Reason.—Let C, Fig. 169, be the centre of the circle, and H E, E F, E G, be three consecutive sides of a polygon described according to the method just enunciated, D, A, B being their points of contact with the circle; then D, A, B are three of the angular points of an inscribed regular polygon, and the arcs D A, A B, are equal to one another, as also are the angles D C A, A C B. The angles at D, A, and B are (Theor. 20) right angles; therefore (Theor. 12), $CD^2+DE^2=CE^2=CA^2+AE^2$, and, since $CD^2 = CA^2$, DE^2 must be equal to AE^2, and D E to E A. The triangles C D E, C E A, have, therefore, their sides equal, each to each, and are consequently equal in all respects. The angles A C E and E C D are therefore equal to one another, and A C E is the half of A C D. In the same manner, A C F is half of A C B; hence, since the angles D C A and A C B are equal to one another, A C E and A C F are also equal to one another; the right angles E A C and C A F are also equal to one another, and the side C A is common to the two triangles C E A and C A F; therefore, these two triangles are equal in all respects. Hence E A is equal to A F, and E F is double of E A. In like manner, E H is double of E D; and, therefore, since A E is equal to E D, E F is equal to E H. In like manner, the other sides of the described figure are each equal to E F or E H, and the figure is equilateral. Again, the angles C E A and C F A being equal to one another, their doubles, the angles H E F and E F G, are equal to one another; and in like manner, the other angles of the described figure are equal to H E F or E F G, and the figure is equiangular.

Exercises.

(1.) Describe a circle about a square whose sides are each 1 inch. Describe a regular pentagon about the circle, and measure its side and diagonal.—*Ans.* 1 inch; 1·62 inches.

(2.) Describe a regular hexagon about a circle 2 inches in diameter, and measure one of its sides.—*Ans.* 1·15 inches.

209 Problem 101.—*To inscribe a circle in, and to describe a circle about, a given regular polygon.*

Bisect two of the adjacent angles of the polygon by the straight lines A C, B C, Fig. 170, meeting in C, and from C draw C D perpendicular on a side A B; then C will be the centre both of the inscribed and circumscribed circles; and C D and C A will be their radii.

Reason.—Join C with the angular point E; then, C A, A E are equal to C A, A B, each to each, and the angle C A E to the angle C A B, therefore C E A is equal to C B A, that is, to half an angle of the figure. Hence the angle A E F is bisected by C E, and, similarly, all the other angles of the figure are bisected by straight lines meeting in C.

Draw C G perpendicular to A E; then, since the angle C A G is equal to the angle C A D, the right angle C G A to the right angle C D A, and the side C A common to the two triangles C A G and C A L; therefore, these two triangles are equal in all respects, and the side C G is equal to the side C D. In like manner, the perpendiculars from C upon the other sides of the polygon are equal to C G or C D, and the circle described from centre C, with any one of them as radius, will pass through the extremities of all of them, and (Theor. 20) touch the sides of the given polygon, in which, therefore, the circle will be inscribed.

Again, the angles, C A B, C B A, being each equal to half an angle of the polygon, are equal to one another; therefore, C A is equal to C B. In like manner, the lines drawn from C to the other angular points of the polygon are each equal to C A or C B, and the circle described from centre C, with radius equal to any one of them, will pass through the extremities of all the others and be described about the given polygon.

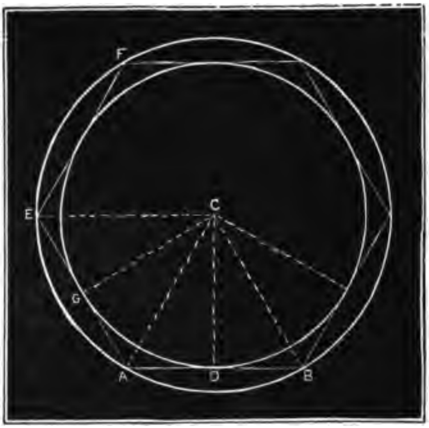

Fig. 170.

Exercises.

(1.) A regular pentagon is described with sides of 1 inch. Inscribe a circle in it, and describe another about it; and measure their diameters.—*Ans.* 1·38 inch; 1·7 inch.

(2.) Inscribe a circle in, and describe a circle about, a regular hexagon of $\frac{3}{4}$ inch side.

(3.) Inscribe a regular heptagon in a circle of 2·4 inches diameter; and inscribe a circle in the heptagon.

211. Problem 102.—*To inscribe a circle in a given sector of a circle.*

Bisect the angle B A C, Fig. 171, by the straight line A D, cutting the arc of the sector in the point D; through D draw

E F at eight angles to A D, and consequently touching the arc B C at the point D; produce A B, A C, to meet E F in the points E and F; inscribe (Prob. 88) a circle in the triangle A E F; then this will be the circle required. The centre is found, therefore, by bisecting either of the angles A E F, A F E.

Reason.—The centre of the circle inscribed in the triangle A E F is on the line A D, bisecting the angle E A F (Prob. 64)·

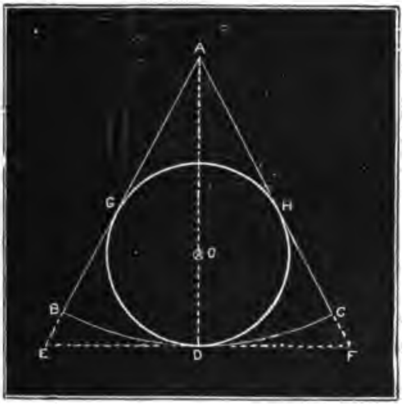

Fig. 171.

and, since O D is perpendicular to E F, D is the point of contact of this circle with E F; therefore, E F is a common tangent to the circles B D C and G D H at the point D, and the circles touch one another at this point.

EXERCISES.

(1.) The sides of a sector are 2 inches, and they include an angle of 50°; inscribe a circle in the sector.

(2.) The sides of a triangle are 1 inch, 2 inches, and 3 inches; inscribe in a circle of 3 inches diameter a triangle equiangular to the given triangle. Inscribe circles in the sectors formed by drawing radii to the angular points of the triangle.

212. PROBLEM 103.—*To inscribe in a given circle three equal circles to touch one another and the given circle.*

Open the points of the compasses to a distance equal to the radius of the given circle, and with this distance mark off two arcs D A and D B, Fig. 172, on the circumference; draw the three radii O A, O B, O C, the last being in a line with the point D; inscribe circles in the three sectors A O B, B O C, C O A; these shall be the circles required.

Reason.—By the construction, the three circumferences A B,

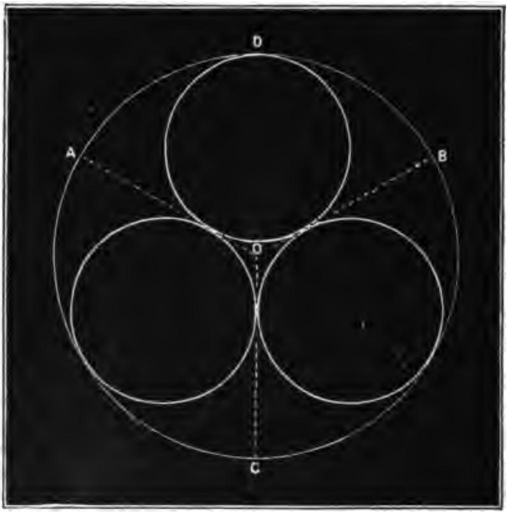

Fig. 172.

B C, C A, are equal to each other, and the sectors A O B, B O C, and C O A, are both similar and equal; the circles inscribed in them will therefore be equal, and will touch each other, since they will touch the radii O A, O B, O C, at equal distances from the centre.

EXERCISE.

The diameter of a given circle is 3 inches; inscribe in it three equal circles to touch one another and the given circle.

213. PROBLEM 104.—*To inscribe a square in a given segment of a circle.*

Bisect the base A B, Fig. 173, of the given segment in the point C; upon A B describe a square A B D E; join C D and C E, cutting the circumference in the points F and G; join F G, and draw G H and F K parallel to A E or B D; then F G H K will be the square required.

Reason.—From C draw C L perpendicular to A B; then C L is (Theor. 9) parallel to A E and B D, bisects (Theor. 11) D E at right angles, and passes through the centre O of the circle. From O draw O M and O N perpendicular to C D and C E respectively, and join O F and O G. Then, since the angle O C M is equal to the angle O C N, the right angle O M C equal to the right angle O N C, and the side O C common to the two triangles C O M and C O N, therefore (Theor. 3) C M is equal to C N, and O M to O N. Again, because O F is equal to O G, the squares on O M, M F are equal (Theor. 12) to the squares on O N, N G; and therefore, since O M is equal to O N, M F is also equal to N G. But C M has been proved equal to C N; therefore the whole C F is equal to the whole C G; and since, by the construction, the angles F C K and C K F are respectively equal to the angles G C H and C H G, therefore (Theor. 3) C K is equal to C H, and K F to H G. Hence H K is double of C K; and F K and G H being both equal and parallel, F G and H K are also equal and parallel. Now F K being parallel to B D, the triangles C K F and C B D are (Theor. 9) equiangular, and (Theor. 18) have their sides about equal angles proportionals; therefore F K is to K C as D B to B C; and therefore, since B D is double of B C, F K is double of C K, and consequently equal to K H. Hence the parallelogram F G H K is equilateral, and being also rectangular, it is a square.

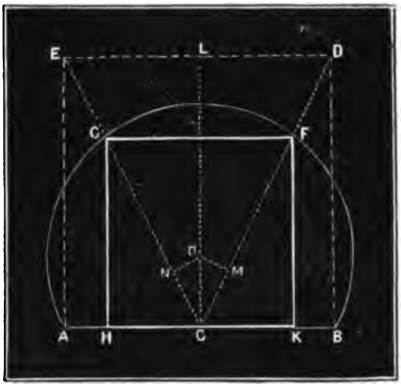

Fig. 173.

EXERCISE.

The diameter of a semicircle is 2 inches; inscribe in it a square.

CHAPTER VII.

ON EQUIVALENT AND SIMILAR FIGURES.

THEOREMS.

214. **Theor. 29.**—Parallelograms and triangles upon the same or upon equal bases, and between the same parallels, are equal to one another. (Eu. I. 35—38.)

215. **Theor. 30.**—If a parallelogram and a triangle be upon the same base and between the same parallels, the parallelogram shall be double of the triangle. (Eu. I. 41.)

216. **Theor. 31.**—Triangles and parallelograms of the same altitude are one to the other as their bases. (Eu. VI. 1.)

217. **Theor. 32.**—Similar triangles and polygons are one to the other in the duplicate ratio of their homologous sides. Hence, if three straight lines be proportionals, as the first is to the third, so is any rectilineal figure described upon the first to the similar and similarly described rectilineal figure upon the second. (Eu. VI. 19, 20.)

218. **Theor. 33.**—In any right-angled triangle the rectilineal figure described upon the hypothenuse is equal to the similar and similarly described figures upon the sides. (Eu. VI. 31.)

219. **Theor. 34.**—Circles are to one another as the squares of their diameters. (Eu. XII. 2.)

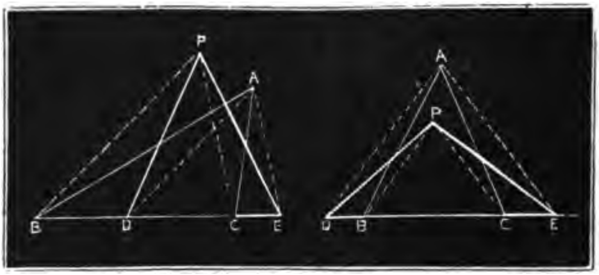

Fig. 174.

220. **Problem 105.**—*To construct a triangle equivalent to a given triangle, and having a given vertex or angular point.*

From the given point P, Fig. 174, draw P B and P C to the extremities of a side of the given triangle; from the angle A, opposite to B C, draw A D, A E, parallel to P B, P C respectively; join P D, P E; then P D E shall be the required triangle.

Reason.—Join A P. The triangles P A B, P D B, being on the same base, P B, and between the same parallels, P B, A D, are equal (Theor. 29); therefore, the quadrilateral D P A C is equal to the triangle A B C. In like manner, the triangles P A C, P E C, are equal, and, therefore, the triangle P D E is equal to the quadrilateral D P A C, that is, to the triangle A B C.

If the given point P be on one of the sides the problem is considerably simplified.

EXERCISES.

(1.) The sides of a triangle are 2 inches, 2¾ inches, and 3 inches; construct equivalent triangles having their vertices in the middle points of the sides.

(2.) Construct triangles equivalent to the same triangle from points on a line bisecting one of the angles, at distances of ½ inch from the angular point.

221. PROBLEM 106.—*Given the altitude of an isosceles triangle equivalent to a given triangle, to construct it.*

Draw P D, Fig. 175, bisecting the base, B C, of the given triangle at right angles in the point D, and make P D equal to the given altitude; from A draw A E parallel to B C, intersecting P D in E; draw E F, E G, parallel to P B, P C respectively; join P F, P G; then P F G shall be the required triangle.

Reason.—If E B and E C be joined, the triangle E B C will (Theor. 29) be equal to A B C; and P F G is equal to E B C by the preceding problem.

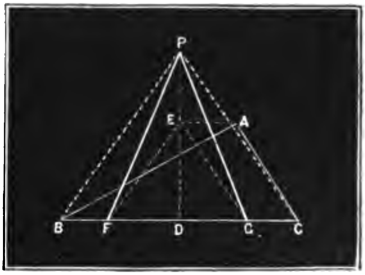

Fig. 175.

EXERCISE.

The base of a triangle is 2 inches, and the angles at the base 40° and 50° respectively; construct an equivalent isosceles triangle, 1½ inches high.

222. **Problem** 107.—*Given the base of an isosceles triangle equivalent to a given triangle, to construct it.*

Bisect a side, B C, of the given triangle at right angles by P D; set off D F, D G, each equal to half the given base; draw A E parallel to B C; through B or C draw B P or C P, parallel to F E or G E; join P F, P G; P F G shall be the triangle required.

Reason.—Identical with that given for last problem.

Exercise.

Construct an isosceles triangle, with a base of 1¼ inches, equivalent to a right-angled triangle, whose base and altitude are 1¼ inches and 1 inch respectively.

223. **Problem** 108.—*Given the equal sides of an isosceles triangle equivalent to a given triangle, to construct it.*

From A, Fig. 176, one of the angular points of the triangle, set off on a side, produced if necessary, A D, equal to the given side of the required triangle; construct (Prob. 105) the triangle A D E, equivalent to A B C; from centre A, with radius A D, describe the circle D F F′; through E draw E F F′, parallel to A D, cutting the circle D F F′ in F and F′; then A D F, or A D F′, will be the required triangle.

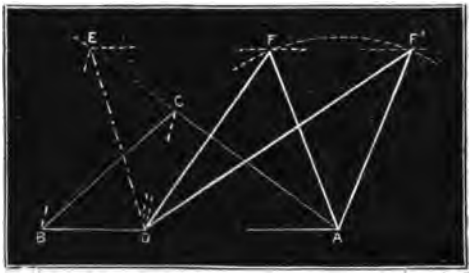

Fig. 176.

Reason.—The triangles, A D F, A D F′, are (Theor. 29) each of them equal to A D E, that is, to A B C.

Exercise.

Construct an isosceles triangle with sides of 2 inches, equivalent to the triangle whose sides are 1 inch, 1·4 inches, and 1·7 inches.

224. Problem 109.—*Given an angle, and one of the sides containing this angle of a triangle, equivalent to a given triangle, to construct it.*

From the extremity B, Fig. 177, of one of the sides B C of the given triangle, draw B D, making the angle C B D equal to the given angle; on B C or B D, produced if necessary, set off B E equal to the given side; draw A D parallel to C B, and construct (Prob. 105) the triangle B E F equivalent to the triangle B C D, then B E F shall be the required triangle.

Reason.—B D C is (Theor. 29) equivalent to B A C, and B E F is equivalent to B D C.

Exercise.

Construct a right-angled triangle, having one of its sides 2 inches long, equivalent to an equilateral triangle with sides [illegible] inches long.

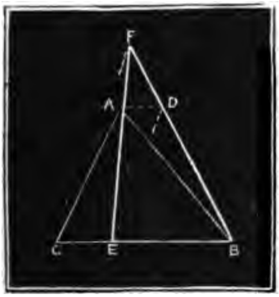

Fig. 177.

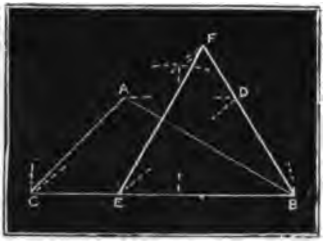

Fig. 178.

225. Problem 110.—*Given the angles of an isosceles triangle equivalent to a given triangle, to construct it.*

Draw B D, Fig. 178, making with B C, a side of the given triangle, the angle C B D equal to the given vertical angle of the required triangle; from A draw A D, parallel to B C; take (Prob. 33) B E, a mean proportional between B C and B D; construct (Prob. 105) the triangle B E F equivalent tc B C D; then B E F shall be the required triangle.

Reason.—Since C F is by the construction (Prob. 105) parallel to E D, B C is to B E as B F to B D (Theor. 15); but B C is to B E as B E to B D; therefore B F is equal to B E, and the triangle B E F is isosceles; and it has been made equal to B D C, that is, to B A C.

EXERCISE.

Construct a right-angled isosceles triangle equivalent to the triangle whose sides are 1 inch, 2 inches, and 3 inches.

226. PROBLEM 111.—*To construct an equilateral triangle equivalent to a given triangle.*

This is to construct an isosceles triangle with a vertical angle equal to two-thirds of a right angle, equivalent to the given triangle.

EXERCISE.

Two sides of a triangle are 1·5 and 2·2 inches long respectively, and contain an angle of 75°; construct an equivalent equilateral triangle.

227. PROBLEM 112.—*To bisect a triangle by a line drawn through a given point in one of its sides.*

If the given point P be the middle point of the side A B, Fig. 179, the line joining this point with the opposite angle is the required line; but, if not, let A be the extremity of A B, nearest to P; bisect the side B C opposite to A in the point D; from A draw A E, parallel to P D; join P E; then P E will be the required line bisecting the triangle A B C.

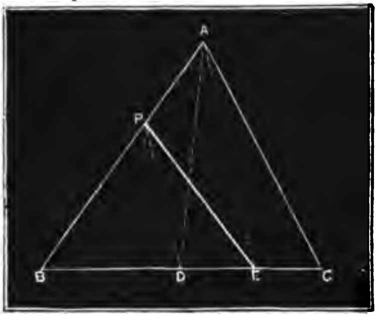

Fig. 179.

Reason.—If A D be joined, A B D is equal to A D C (Theor. 29), and, therefore, A B D is half of A B C; but B P E is equal to A B D (Prob. 105); therefore, P E bisects the triangle A B C.

EXERCISE.

The sides of an equilateral triangle are 2 inches long, bisect it by a line drawn through a point in a side at $\frac{3}{10}$ inch from one of its angles.

228. PROBLEM 113.—*To bisect a triangle by lines drawn from any point within it.*

METHOD I.—With the given point P as a vertex, construct the triangle P D E, Fig. 180, equivalent to the triangle A B C (Prob. 105); bisect D E in F; join P A, P F, then P A and P F will be the required lines bisecting the triangle A B C.

Reason.—P D E being equivalent to A B C, and being bisected by P F, P D F is the half of A B C; but P A B is (Theor. 29) equal to P D B; therefore, P A B F is equal to P D F, or to the half of A B C.

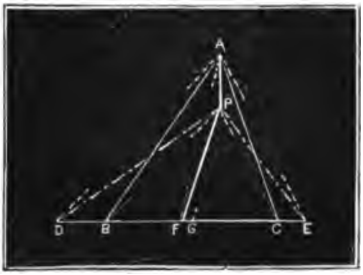

Fig. 180.

METHOD II. — Bisect B C in the point G; through A draw A F parallel to P G; join P A, P F.

Reason. — By the construction, A P F is made equal to A G F (Theor. 29); therefore, P A B F is equal to A B G, that is, to half A B C.

EXERCISE.

Two sides of a triangle measure 2 inches and 3 inches respectively, and contain a right angle; bisect the triangle by lines drawn from the middle point of the perpendicular, let fall from the right angle on the hypothenuse.

229. PROBLEM 114.—*To bisect a triangle by a line drawn parallel to one of the sides.*

B C being the side of the triangle A B C, Fig. 181, to which the bisecting line is to be parallel, bisect A B, one of the other sides, in the point D; from A set off (Prob. 33) A E, a mean proportional between A B and A D; then E F, drawn through E, parallel to B C, will bisect the triangle A B C.

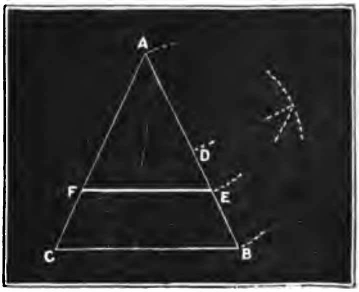

Fig. 181.

Reason.—Since A B is to A E as A E to A D, therefore (Theor. 32) the triangle A B C is to the similar triangle A E F as A B is to A D, or as 2 : 1; therefore A B C is double of A E F, or A B C is bisected by E F.

Exercise.

The sides of a triangle are 1·2, 1·5, and 1·8 inches respectively; bisect it by a line parallel to the longest side, and measure the length of the bisecting line.—*Ans.* 1·27 inches.

230. **Problem** 115.—*To bisect a triangle by a line drawn perpendicular to one of the sides.*

B C, Fig. 182, being the side to which the bisecting line is to be perpendicular, from A draw A D perpendicular to B C; bisect B C in E, and on B D, the larger of the segments into which the base is divided by the perpenpendicular, set off B F, a mean proportional between B E and B D; then F G, drawn through F, perpendicular to B C, shall be the required bisecting line.

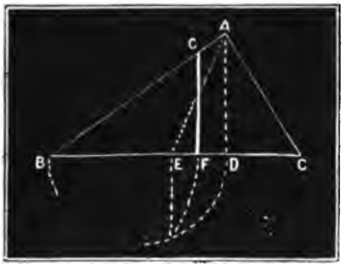

Fig. 182.

Reason.—Since B D is to B F as B F to B E, therefore (Theor. 32) the triangle B D A is to the triangle B F G as B D to B E; but (Theor. 31) as B D is to B E, so is the triangle B D A to the triangle B E A; therefore B D A is to B F G as B D A to B E A; therefore B F G is equal to B E A, or to the half of A B C.

Exercise.

Bisect the triangle whose sides are 3 inches, 4 inches, and 5 inches, by a line perpendicular to the longest side, and measure the length of the bisecting line.—*Ans.* 2·12 inches.

231. **Problem** 116.—*To divide a triangle into a given number of equal parts, by lines drawn from a given point within it.*

Method I.—Divide B C, Fig. 183, into the given number of equal parts, and let B D be one of them; join A D; then A D P is equivalent to one of the required parts of the triangle. Construct the triangle P B E equivalent to A B D, and having the given point P for its vertex; then P B E is one of the required parts of the triangle. Set off along B C, produced both ways, if necessary, as many parts equal to B E as the number of parts into which the triangle is to be divided; from the divisions beyond B draw parallels to P B to meet A B, and from the divisions beyond C draw parallels to P C, as G H, to meet A C, join P F, P H, &c.; then the triangle shall be divided as required.

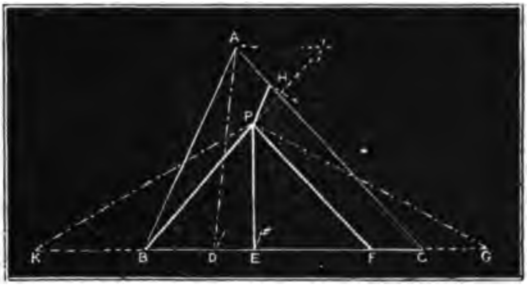

Fig 183.

Reason.—The triangles P B E, P E F, P F G, &c., are (Theor. 29) all equal, and are therefore each equal to one of the required parts of the triangle; the triangle P H C is equal to the triangle P G C; and, therefore, the quadrilateral P H C F is equal to the triangle P F G, or to one of the required parts of he triangle.

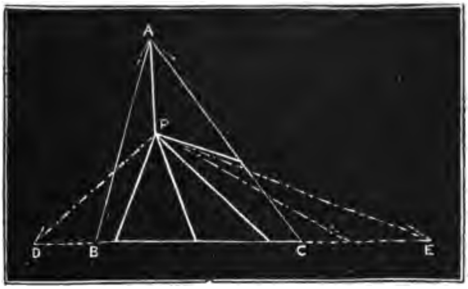

Fig. 184.

METHOD II.—Construct (Prob. 105) the triangle P D E, Fig. 184, equivalent to A B C; divide D E into the same number of equal parts as the number into which the given triangle A B C is to be divided; from the points of division beyond B and C draw parallels to P B and P C to meet A B and A C; join P with A, and with the points thus determined on the sides of the triangle.

Reason.—Exactly like that given for Method I.

EXERCISES:

(1.) Two sides of a triangle are 2 inches and 2½ inches long respectively, and contain an angle of 60°; divide the triangle into four equal parts, by lines drawn through the middle point of the shortest side.

(2.) The equal sides of an isosceles triangle measure each 3 inches, and the base measures 2 inches; divide the triangle into five equal parts by lines drawn from the centre of the inscribed circle.

232. PROBLEM 117.—*To make a square equivalent to a given triangle.*

Construct (Prob. 110) a right-angled isosceles triangle, E C F, Fig. 185, equivalent to A D C, the half of the given triangle A B C; then E C shall be the side of the required square.

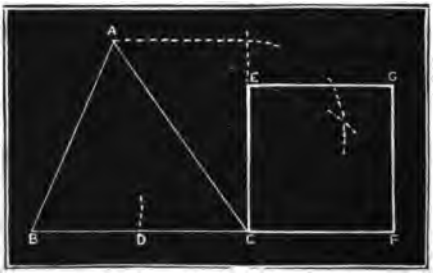

Fig. 185.

Reason.—The square C G and triangle A B C are each of them double of the triangle E C F, and are therefore equivalent to one another.

EXERCISE.

Construct a square equal to an equilateral triangle, each side of which measures 2 inches.

233. **Problem** 118.—*To construct a parallelogram that shall be equivalent to a given triangle, and shall also answer other conditions.*

Construct a triangle which shall be equivalent to half the given triangle, and shall also answer the given conditions. The triangle thus constructed will form one-half of the required parallelogram, which will be completed by drawing parallels to the sides of the triangle.

Exercises.

The three sides of a triangle measure 1½ inches, 2 inches, and 2½ inches respectively.

(1.) Upon a line 1 inch long construct a rectangle equal to the triangle.

(2.) Construct a rhombus equal to the triangle, and having the length of one of its diagonals 1¾ inches.

(3.) Upon a line 2 inches long construct a rhombus equal to the triangle.

(4.) Construct a parallelogram equal to the triangle, having one of its sides 2 inches long, and one of its angles 60°.

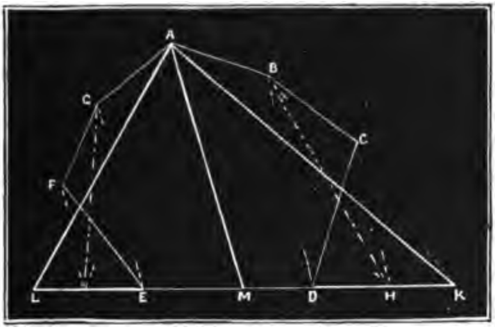

Fig. 186.

234. **Problem** 119.—*To construct a triangle equivalent to any rectilineal figure.*

This is called reducing the figure to a triangle, and the simplest mode of performing the reduction is to select one of the angular points of the figure for the vertex of the triangle, and the prolongation of one of the sides of the figure for the base of the triangle.

Let then the point A, Fig. 186, of the rectilineal figure A B C D E F G be assumed for the vertex of the triangle, and the side D E produced both ways for the base; through C draw C H parallel to B D, and join B H; through B draw B K parallel to A H, and join A K; then A K will be one side of the triangle. Proceeding in like manner to eliminate the angular points F and G, the other side, A L, of the triangle will be determined.

Reason.—The triangle B H D is (Theor. 29) made equal to the triangle B C D, and, therefore, the figure A B H E F G is equivalent to the figure A B C D E F G. Again, the triangle A K H is made equal to the triangle A B H, and A K E F G is equivalent to the figure A B H E F G, and thus the sides A B, B C, C D have been replaced by the single side A K. In like manner, the sides E F, F G, G A are replaced by the single side A L, and the seven-sided figure A B C D E F G is reduced to the triangle A L K.

From the various problems which have already been solved on the construction of equivalent triangles, there will be no difficulty in modifying this problem so as to place the vertex at a point in one of the sides, or in any other desired position.

If the base L K be bisected in the point M, it is manifest that the line A M, which bisects the triangle A L K, will also bisect the figure A B C D E F G. Also the figure may be bisected by a line drawn from a given point in one of the sides, by constructing an equivalent triangle, with the given point for its vertex, and bisecting the triangle by a line drawn through this vertex. And, again, the figure may be bisected by lines drawn from any given point within it, by constructing an equivalent triangle, with its vertex at one of the angular points, or on one of the sides of the figure, and having the given point within it, since the lines drawn through the given point to bisect this triangle will also bisect the figure.

235. PROBLEM 120.—*To construct a square equivalent to a given rectilineal figure.*

Reduce the figure to a triangle, and construct a square equivalent to the triangle.

EXERCISES.

(1.) On a line 2 inches long, construct a regular hexagon; reduce it to a triangle; construct (1) an equivalent equilateral triangle; (2) an equivalent square.

(2.) Inscribe a regular octagon in a square whose side is 3 inches; construct a square equal to the octagon.

(3.) Construct a polygon, A B C D E F, from the following condition—

The side A B = 2 inches. Angle A B C = 143°
,, B C = 1·7 ,, ,, D E F = 118°
,, C D = 2·2 ,, Diagonal B D = 3 inches.
,, D E = 1·5 ,, ,, C E = 3·3 ,,
,, E F = 2 ,,

Bisect the polygon (1) by a line drawn through A; (2) by lines drawn from P, the vertex of the equilateral triangle described upon A B. State the lengths of the bisecting lines; also the length of the side A F; the length of the diagonal A D; and the magnitude of the angle E F A.

236. Problem 121.—*Upon a given straight line to construct a polygon similar and similarly situated to a given polygon.*

Method I.—C D, Fig. 187, being the side of the given polygon corresponding to the side of the required figure, which the given line A B is to form, divide the polygon into triangles by lines drawn from one extremity D of C D to the other angular points of the polygon. Make the angles B A F and A B F respectively equal to the angles D C E and C D E; then the third angle A F B will be equal to the third angle C E D, and the triangle A F B will be equiangular, and therefore similar (Theor. 18) to the triangle C E D. Again, make the angles B F H and F B H respectively equal to D E G and E D G; then the figure A F H B will be similar and similarly situated to the figure C E G D.

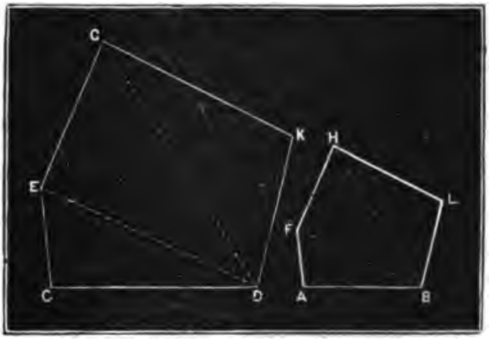

Fig. 187

Reason.—The triangles A F B and F H B being respectively similar and similarly situated to the triangles C E D and E G D, the angle A F B is equal to the angle C E D, and B F H to D E G; therefore the whole angle A F H is equal to the whole angle C E G. In like manner, the angles A B H and C D G are equal. Also the angles at A and H are respectively equal to the angles at C and G; and, therefore, the figures A F H B and C E G D are equiangular. Again, since A F is to F B as C E to E D, and F B to F H as E D to E G; therefore A F is to F H as C E to E G, and the sides about the equal angles A F H and C E G, are proportional. In like manner, the sides about the equal angles A B H and C D G are proportional; also from the similarity of the triangles, the sides about the angles at A and H are respectively proportional to the sides about the angles at C and G. Hence the figures A F H B and C E G B, being equiangular, and having their sides about the equal proportionals, are (24) similar.

Proceeding in the same manner to add to the figure A F H B other triangles, similar and similarly situated to the remaining triangle into which the given polygon C E G K D has been divided, a polygon will be described on A B, similar and similarly situated to the given polygon.

Method II.—In this, as in Method I, the required polygon is formed by building it up of triangles similar and similarly situated to those into which the given polygon is divided as before; but instead of forming these triangles, by making them equiangular, the sides about each of their angles are made proportional. Upon a straight line, Q R, Fig. 188, take Q R equal to C D, and Q S equal to A B; from centre Q, with radii Q R and Q S, describe concentric arcs, R U and S W; in R U place the chords R T and R U, equal respectively to the sides C E and D E of the triangle C E D; join Q R, Q T, cutting the arc S W in V and W; then the chords S V and S W will be the required lengths for the sides A F, B F, of the triangle A F B.

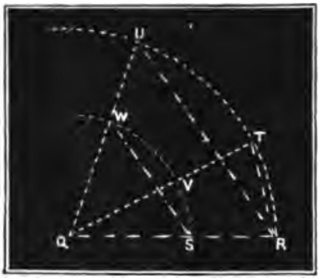

Fig. 188.

Reason.—Q R being equal to Q T, and Q S to Q V, the sides of the triangles Q S V and Q R T about the common angle at Q are proportionals; therefore (Eu. VI. 6), these triangles are similar, and Q R is to R T as Q S to V S. In like manner, Q R is to R U as Q S to S W. Hence, Q R, R T, and R U, being equal respectively to C D, C E, and D E, and Q S being equal to A B, if A F and B F be made respectively equal to S V and S W, the sides of the triangles A F B and C E D, about each of their angles, will be proportionals; and, therefore (Eu. VI. 5), these triangles will be equiangular and similar. In like manner, by setting off on the arc R U chords equal to the sides of the other triangles into which the given polygon is divided, chords upon the arc S W will be determined equal to the required lengths of the sides of the triangles, which will build up the similar and similarly situated figure on A B.

EXERCISES.

(1.) The sides of a triangle being 2⅓ inches, 3⅓ inches, and 5 inches long respectively, describe a similar triangle, whose longest side shall be the side of an equilateral triangle described in a circle of 2 inches diameter.

(2.) Construct a polygon, A B C D E F G, from the following conditions:—

A B = 1·25 inches. A G = 1·6 inches.
B C = 2·2 „ G F = 1·5 „
C D = 2·2 „ F E = 1·5 „
Diagonal A E = 3·7 inches.
A B C = 155° B A G = 110°
B C D = 115° B A E = 70°

On a line, 1·4 inches long, construct a polygon similar to the above polygon, so that the given line may form the side corresponding to D E. Give the measurements of D E and C F, and of the corresponding lines on the similar figure described on the given line.

(3.) The sides A B, A C, of a triangle are each 2 inches long, and contain an angle of 30°. A square, A D E C, is described on the side A C, and another square, B C F G, on the base B C; and E F being joined, an irregular hexagon, A D E F G B, is formed. Take a line 2 inches long to form the side corresponding to E F, and construct upon it a similar hexagon. Measure the length of the diagonal D G, and of the corresponding diagonal in the similar hexagon.—*Ans.* 4·2 inches; 3·5 inches.

237. PROBLEM 122.—*To construct a rectilineal figure which shall be similar to one, and equivalent to another given rectilineal figure.*

Reduce (Prob. 119) half the figure F, Fig. 189, to which the required figure is to be similar, to a triangle having its base in a line with one of its sides A B, and construct (Prob. 109) on A B an equivalent right-angled triangle A B C. Again, reduce half the figure G, to which the required figure is to be equal, to a triangle, and construct an equivalent right-angled triangle, C B D, on B C; then will A B D be a straight line, and the triangles A B C, C B D, will have the same altitude as B C. Find B E, the mean proportional between A B and B D; on B E, or on any line equal to B E, construct a figure similar and similarly situated to the given figure, so that B E may correspond to A B; then the figure thus described will be the figure required.

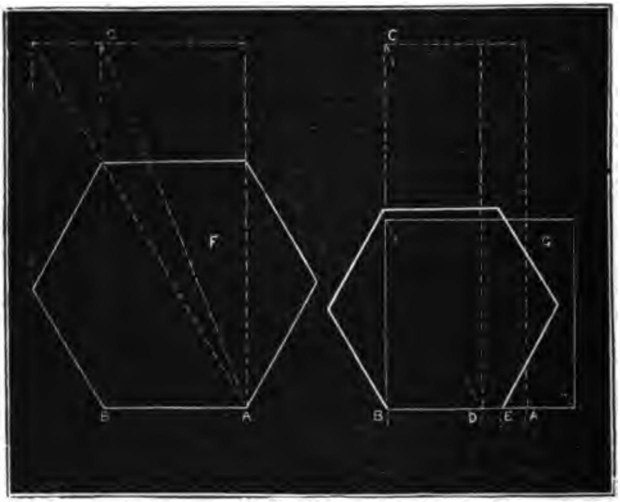

Fig. 189.

Reason.—Because A B is to B E as B E to B D; therefore (Theor. 32), as A B is to B D, so is the figure on A B to the similar and similarly described figure on B E; but as A B is to B D, so also is the triangle A B C to the triangle C B D (Theor. 29); therefore, as the figure on A B is to the similar figure on B E, so is the triangle A B C to the triangle C B D. But the triangle A B C was made equivalent to the figure on A B; therefore, also, the figure on B E is equivalent to the triangle C B D, that is, to the given figure.

EXERCISES.

(1.) Construct a regular hexagon equivalent to a square of 2 inches side.

(2.) The sides of a triangle measure 4 inches, 3½ inches, and 2½ inches respectively; construct an equivalent trapezoid, having the longest parallel side three times the length of the shorter, and the other side inclined at angles of 45°.

(3.) The sides of a trapezium measure 1 inches, 2 inches, 3 inches, and 4 inches, and the angle between the two longest sides is 30°; construct a regular octagon equivalent to the trapezium.

(4.) Construct a regular pentagon equal to the same trapezium.

(5.) Construct a triangle equivalent to an equilateral triangle of 3 inches side, and having two of its angles 75° and 45° respectively.

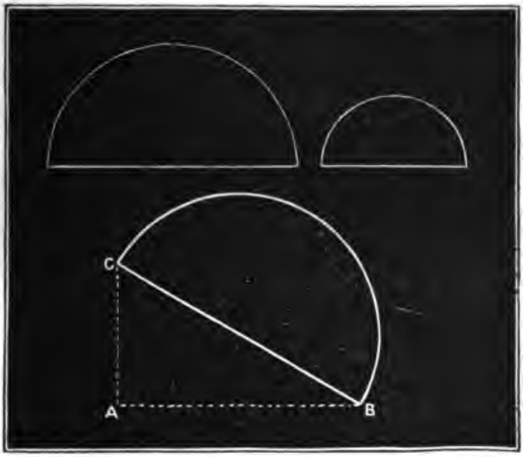

Fig. 190.

ADDITION AND SUBTRACTION OF SIMILAR FIGURES.

238. PROBLEM 123.—*To construct a figure which shall be equivalent* (1) *to the sum,* (2) *to the difference of two similar and similarly described figures.*

(1.) Construct the right-angled triangle B A C, Fig. 190, having its sides, A B, A C, equal to homologous or corresponding sides of the two given figures; then shall the similar and similarly described figure on the hypothenuse B C be equivalent to their sum.

(2.) Construct the right-angled triangle B A C, Fig. 191, having its hypothenuse B C equal to a side of the largest of the two given figures, and A C, one of its sides, equal to the homologous or corresponding side of the smaller; then shall the similar and similarly described figure on the other side, A B, be equivalent to the difference of the two figures.

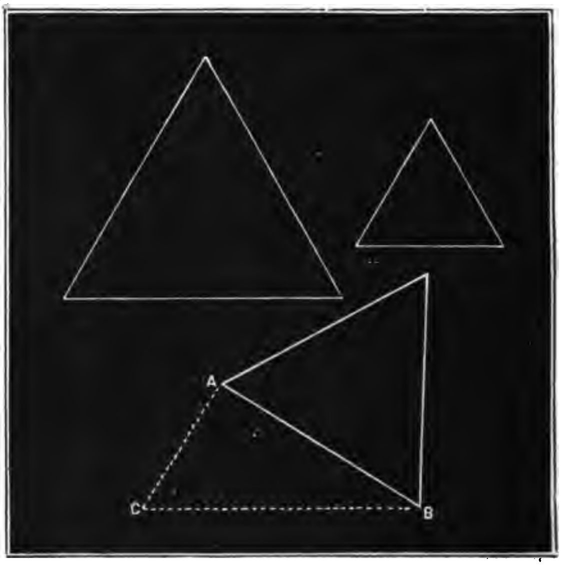

Fig. 191.

Reason.—The rectilineal figure described upon B C is (Theor. 33) equal to the sum of the rectilineal figures similar and similarly described upon A B and A C; and, consequently, the rectilineal figure on A B is equal to the excess of the similar and similarly described figure upon B C, over that described upon A C. Again, since circles are to another as the squares of their diameters (Theor. 34), and the square upon B C is equal to the sum of the squares upon A B and A C; therefore, the circle having B C for its diameter, is equal to the sum of the two circles having A B and A C for their diameters.

Lastly, the same relation will also hold good for semicircles, or any equal portions of circles, such as similar segments or similar sectors.

EXERCISES.

(1.) Construct an equilateral triangle equivalent to the sum of two equilateral triangles, one inscribed in a circle of 2 inches diameter and the other described on the diameter.

(2.) Construct an equilateral triangle equivalent to the difference between the triangle just constructed and the equilateral triangle described about the circle.

(3.) The angles of a triangle are 45°, 60°, and 75°, and the perpendicular from the largest angle upon the opposite side measures 1 inch; construct (1) a square equivalent to the squares described upon the two shortest sides of the triangle; (2) a square equivalent to the difference between this square and that described on the largest side of the triangle.

(4.) A square is inscribed in an equilateral triangle whose sides are each $2\frac{1}{2}$ inches long; construct circles equivalent to the sum and difference of the circles described upon a side of the triangle, and a side of the inscribed square as diameters.

MULTIPLICATION AND DIVISION OF FIGURES.

239. PROBLEM 124.—*To construct a similar figure having a given ratio to a given figure.*

Take A C, Fig. 192, in the given ratio to A B, a side of the given figure; find A D, a mean proportional between A B and A C; on A D describe a figure similar and similarly situated to the given figure on A B; then the figure thus described shall have to the given figure the given ratio.

Reason.—By the construction, A B is to A D as A D to A C; therefore (Theor. 32), the figure on A B is, to the similar and similarly situated figure on A D as A B to A C, or the figure on A D has to the figure on A B the ratio of A C to A B, that is, the given ratio.

EXERCISES.

(1.) The equal sides of an isosceles triangle measuring each 1·8 inches, and including an angle of 50° construct (1) a similar triangle three times as large; (2) a similar triangle of one-third the size.

(2.) A regular hexagon being described about a circle of 1⅓ inches diameter, construct (1) a regular hexagon of five times the size; (2) a regular hexagon of one-fifth the size.

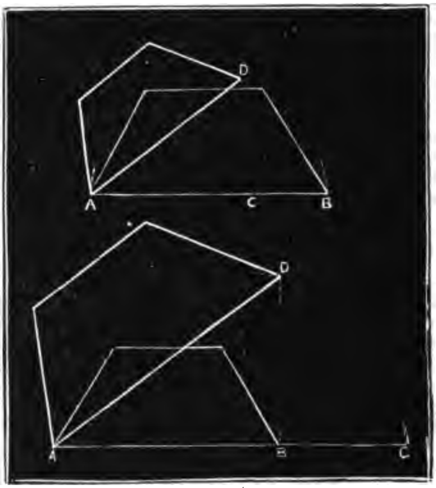

Fig. 192.

(3.) A circle being inscribed in an equilateral triangle, each side of which measures 2 inches, construct (1) a circle to contain seven times the area, (2) a circle to contain one-seventh of the area.

Numerical Representation of Areas.

240. Hitherto figures have been constructed equal in area to other figures, but differing in form, or figures similar in form to others but differing in area. By combining these two classes of problems, figures may readily be constructed, differing, in a given manner, both in form and area, from other given figures.

The modes of determining the numerical representative of the area of a given figure, and of constructing a figure whose area is given by its numerical representative, remain to be considered.

The number representing an area depends upon the unit of area assumed as the standard of comparison. The standards which are employed for this purpose vary with the standards which are used for the units of linear measurements, but are universally the squares described upon the linear units. Thus, the English units of length being the inch, the foot, the yard, &c., the units of area are the squares upon an inch, a foot, a yard, &c.; the French units of area are the squares upon the metre and its multiples and submultiples; and so with other nations, if we know the standard units of linear measure, the squares upon these units will be their units of surface measurement.

241. *To find the number representing the area of a rectangle.*

Multiply together the numbers representing the linear dimensions of two adjacent sides, Fig. 193.

Reason.—If we take a strip of the rectangle one unit in breadth, this will contain as many squares upon a unit of length as there are units of length in the strip, or in one side, A B, of the rectangle; and the entire rectangle will contain as many of these strips as there are units of length in the other side, A C, of the rectangle.

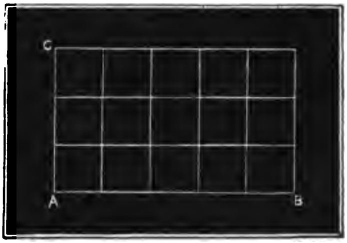

Fig. 193.

242. *Conversely, to construct a rectangle of a given area.*

It is only necessary to split into two factors the number representing the area, and construct the rectangles whose adjacent sides contain the numbers of linear units represented by the factors; thus, the area of a rectangle being stated to be 12 square inches, the sides of the rectangle will be 12 inches and 1 inch, 6 inches and 2 inches, or 4 inches and 3 inches, or 5 inches and $2\frac{2}{5}$ inches, or any two numbers of inches whose product is 12.

243. PROBLEM 125.—*To construct a square to contain an area represented by a given numerical quantity.*

(1.) If the given numerical quantity be a perfect square, either whole or fractional, its square root will be a side of the required square. If the given numerical quantity be not an exact square number, the side of the required square may be found in either of the two following modes.

(2.) By taking two or more square numbers, the sum or difference of which shall be equal to the given number, and applying Prob. 123 to find the side of a square equivalent to such sum or difference.

(3.) By splitting the given number into factors, the product of which would therefore represent the sides of a rectangle having the given area; the mean proportional between these lengths would then be the side of the square required.

The modes will be best illustrated by a numerical example.

To find the side of the square whose area shall be six inches.

Method I.—$6 = 4 + 1 + 1 = 2^2 + 1^2 + 1^2$. Construct therefore a right-angled triangle, having its sides, A B, A C, Fig. 194, 1 inch and 2 inches long; from B draw B D, at right angles to B C, and make this also 1 inch long; join D C; then D C shall be the side of the required square: for the square on B C is equal to the squares on B A, A C; and the square on D C is equal to the squares on B C, B D, and, therefore, to the squares on A B, A C, and D C, which are 1 inch, 2 inches, and 1 inch.

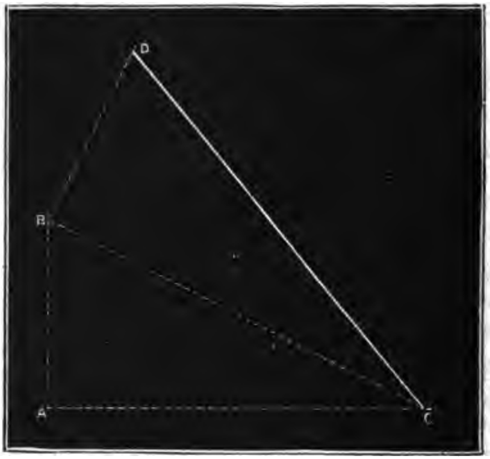

Fig. 194.

Method II.—$6 = \frac{25}{4} - \frac{1}{4} = (\frac{5}{2}^2) - (\frac{1}{2}^2)$. Construct therefore a right-angled triangle, having its side, D B, Fig. 195, ½ inch long, and its hypothenuse, B C, 2½ inches long; then will D C be the side of the square required; for the square on D C is the difference of the squares on B C and D B.

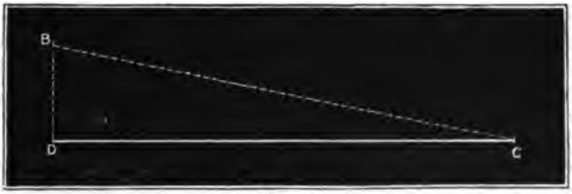

Fig. 195.

Method III.—6 = 3 × 2: the problem, therefore, resolves itself into constructing a square equivalent to the rectangle whose sides are 3 inches and 2 inches respectively. Upon a line, A C, Fig. 196, 3 inches long, describe a semicircle; set off C B, equal to 2 inches; draw B D perpendicular to A C, and join D C; then D C shall be the side of the required square, for D C is a mean proportional (Prob. 33) between A C and C B; hence the square upon D C will be equal to the rectangle A C, C B.

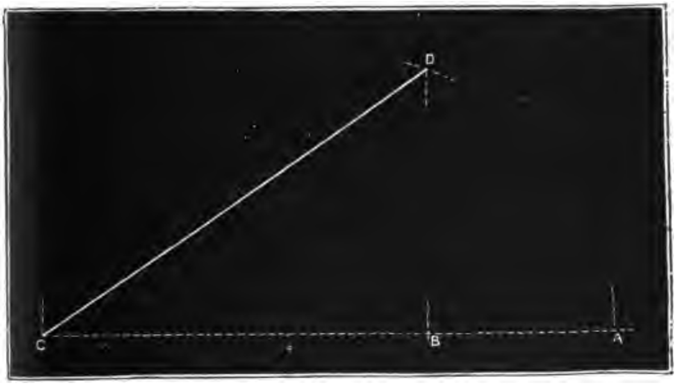

Fig. 196.

244. The length of the line D C is represented by $\sqrt{6}$, a surd

quantity. Hence, by this problem, we are enabled to construct a line the length of which is a surd or irrational quantity, that is, a length which cannot be expressed by any number of units or parts of a unit, no matter how small such parts may be taken.

A rectangle is divided by its diagonal into two equal right-angled triangles. Hence, the area of a right-angled triangle is half the product of the two sides containing the right angle; and, conversely, a right-angled triangle of given area will be constructed by making the length of the sides such that their product amounts to twice the number representing the area.

Any rectilineal figure whatever can be reduced to a rectangle, or to a right-angled triangle, by the methods given in this chapter; and, hence, the area of any such figure can be found.

Again, a figure can be made of any rectilineal form equivalent to a right-angled triangle, or to a rectangle; and, hence, a rectilineal figure can be constructed of any form, so as to contain a given area.

EXERCISES.

(1.) Construct squares whose areas shall be 7 square inches, 11 square inches, and 13 square inches.

(2.) Draw lines whose lengths shall be $\sqrt{2}$ inches, $\sqrt{3}$ inches, and $\sqrt{5}$ inches.

(3.) Construct a rectangle whose sides shall be in the ratio of 8 to 5, and whose area shall be 10 square inches.

(4.) Construct an equilateral triangle whose area shall be 6 square inches.

(5.) Construct a regular pentagon whose area shall be 8 square inches.

(6.) About a circle, 1½ inches in diameter, describe a triangle whose angles shall be 55°, 60° and 65°, and describe a similar triangle, the area of which shall measure 4 square inches.

(7.) Three sides, A B, B C, C D, of a quadrilateral, measure respectively 2 inches, 1·3 inches, and 1·3 inches, and the diagonals A C and B D measure each 2 inches. Measure the length of the other side, A D, and the area of the figure.—*Ans.* 1·08 inches and 1·87 sq. in.

(8.) Construct a quadrilateral similar to that described in example 7, to contain 5 square inches.

245. PROBLEM 126.—*Given the area of a rectangle, and the sum of the sides, to construct the rectangle.*

Determine the side A C, Fig. 197, of the square to contain the

given area; draw A B at right angles to A C, and make it equal to the given sum of two adjacent sides of the rectangle; on A B, as diameter, describe a semicircle; through C draw C D E, parallel to A B; cutting the semicircle in the points D and E; from D or E draw a perpendicular to A B, meeting it in M; then A M, M B, will be the sides of the required rectangle.

Reason.—M D is a mean proportional (Prob. 33) between A M and M B; therefore, the rectangle A M, M B is equal to the square on M D, that is, to the square on A C.

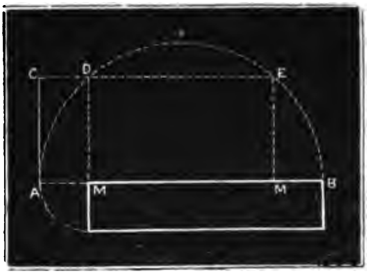

Fig. 197.

246. PROBLEM 127.—*Given the area of a rectangle, and the difference of the adjacent sides, to construct the rectangle.*

Describe a circle whose diameter is equal to the given difference of the sides of the rectangle; draw a line C M touching the circle in any point C, Fig. 198, and make C M equal to the side of the square which contains the given area; through M and O, the centre of the circle, draw M B, cutting the circumference in A and B; then M A and M B will be the sides of the required rectangle.

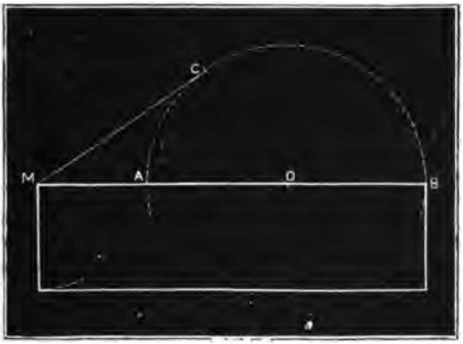

Fig. 198.

Reason.—The difference between M B and M A is the diameter A B, which was made equal to the given difference, and the rectangle, M A, M B, is equal (Theor. 24) to the square on M C, that is, to the given area.

247. The two preceding problems furnish geometrical solutions of quadratic equations.

Problem 126 gives the solution of the equation

$$x^2 - a\,x + b^2 = 0.$$

For this equation may be resolved into

$$x\,(a - x) = b^2.$$

Making, therefore, A B equal to a, and A C equal to b, A M and M B are the values of x, or the roots of the equation.

When b exceeds $\frac{a}{2}$, A C exceeds the radius of the semicircle; C D, therefore, will not cut the semicircle, and there is no real solution of the equation.

By changing x into $-x$ the equation $x^2 - a\,x + b^2 = 0$ is transformed into $x^2 + a\,x + b^2 = 0$. The roots of the latter equation are to be constructed in the same manner as the roots of the former equation, and will only differ from them by the prefix of the negative sign. Thus, the roots of the equation, $x^2 - 5x + 6 = 0$, will be found to be 2 and 3, and the roots of the equation $x^2 + 5x + 6 = 0$ are therefore -2 and -3.

Problem 127 gives the solution of the equation

$$x^2 \pm a\,x - b^2 = 0.$$

For this equation may be resolved into

$$x\,(x \pm a) = b^2.$$

Making, therefore, A B equal to a, and C M equal to b, M A and M B are the values of x and $x + a$, or M B and M A are the values of x and $x - a$. Also, since by changing x into $-x$, the equation $x^2 + a\,x - b^2 = 0$ is transformed into the equation $x^2 - a\,x - b^2 = 0$, and *vice versâ.* — M B is a value of x in the first of these equations, and — M A is a value of x in the second. Thus, M A and — M B are the roots of the equation $x^2 + a\,x - b^2 = 0$, and M B and — M A are the roots of the equation $x^2 - a\,x - b^2 = 0$.

EXERCISES.

(1.) Construct a rectangle such that its area shall be 5 square inches, and the sum of its two adjacent sides 5 linear inches.

(2.) Construct a rectangle such that its area shall be 2 square inches, and the difference of its adjacent sides 1¼ linear inches.

(3.) Solve geometrically the following equations:—

$$(a.)\ x^2 - 5x + 2 = 0.$$
$$(b.)\ 4x^2 + 5x + 1 = 0.$$
$$(c.)\ x^2 + 3x - 5 = 0.$$
$$(d.)\ 5x^2 - 7x - 1 = 0.$$

CHAPTER VIII.

GEOMETRY ON THE GROUND.

248. The difference in the character of the instruments employed for laying down lines upon a large scale upon the ground, from that of the instruments used in the chamber for constructions upon paper, necessitates also some variation in the mode of applying the invariable principles of geometry to the solution of the same problems in the two cases.

The straight-edge, scale, and compass used by the draughtsman are replaced for constructions on the ground by the measuring tape or chain and ranging rods, and the protractor by the prismatic compass, box sextant, or theodolite.

A line on the ground is marked by any two conspicuous objects on it. Lines may be laid out of any length by ranging rods placed at convenient distances. Lines of less length than a chain may be marked by pegs, or, temporarily, for the purposes of geometrical construction, by the arrows supplied with the chain.

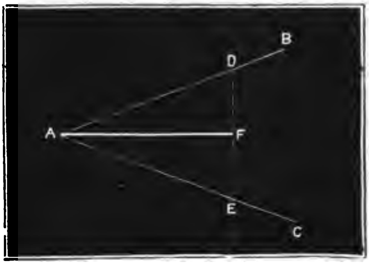

Fig. 199.

249. Problem 128.—*To bisect the angle between two straight lines on the ground.*

From the angular point A, Fig. 199, measure and mark off at D and E, equal distances A D and A E, on the lines A B and A C; measure the distance from D to E, and mark at F the middle point between D and E; then the line A F will bisect the angle B A C.

Reason.—The triangles A D F and A E F will have their sides equal, each to each, and will, therefore, be equal in all respects.

250. PROBLEM 129.—*From a given point upon a given line marked on the ground, to set off a perpendicular to this line.*

METHOD I.—From the given point P, Fig. 200, set off on each side of it, upon the given line, the equal distances P A and P B; find the middle point of a long light cord by doubling it; then fixing the ends of the cord at A and B, take the middle point and retreat with it from the line, until, at the point C, the two parts of the line are stretched with an equal tension; then the line P C will be the perpendicular required.

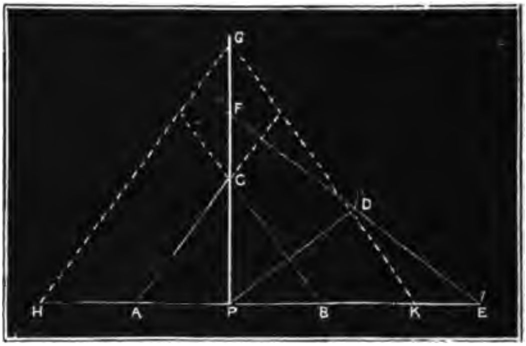

Fig. 200.

Or loop the rings at the ends of the chain over two of the arrows planted at the points A and B, and the end of the fiftieth link, or middle of the chain, will mark the point C as before, the chain being evenly stretched.

Reason.—The two sides C A and C B being equal, the angles C A B and C B A are equal (Theor. 4), and the sides P A and P B being also equal, the triangles C A P and C B P are equal in all respects. Hence the adjacent angles A P C and B P C being equal, P C (17) is perpendicular to A B.

METHOD II.—Fix the first link of the chain at P by looping the ring over one of the arrows; proceed along the given line a distance of 30 links to the point A, and planting there a second arrow, pass over it the ninetieth link; then, taking the fortieth link, and retreating with it to C, until the chain is evenly stretched, P C will be the required perpendicular.

Reason.—See Problem 4, Method II.

METHOD III.—Loop the ends of the chain, or of a long cord, over arrows or pegs planted, one at the given point P and another at any convenient point E, upon the given line; take the middle point of the cord or chain, and retreating with it until, when held at D, the cord or chain is evenly stretched, fix it there on a peg or arrow. Returning now to the point P, take up the end of the chain and proceed with it to the point F in the same straight line with D and E; then, if the cord or chain be again stretched, D F will be equal to D P or D E, and P F will be the perpendicular required.

Reason.—D P, D E and D F being equal to each other, D is the centre and E F the diameter of the circle passing through E, P, and F, and the angle E P F, being the angle in a semicircle, is (Theor. 14) a right angle.

Check.—H and K being any two points on A B, equally distant from P, set out the lines G H and G K from any point G in the perpendicular; then should G H and G K be equal to one another; and if A C and B C be produced to meet G H and G K the produced parts will be equal, and the points of intersection will be at equal distances from G.

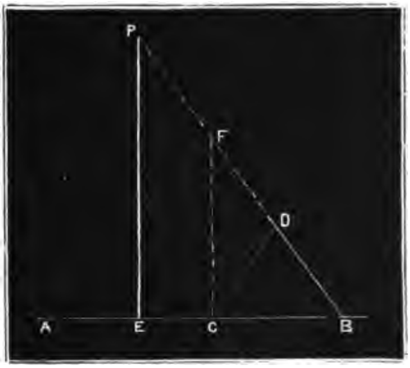

Fig. 201.

251. PROBLEM 130.—*To draw a perpendicular to a given line upon the ground from a given point without the line.*

Measure the oblique distance, P B, Fig. 201, from the given point P to a point taken on the line; fix one end of the chain at B; carry the other end along the given line to C, and the middle point along the line B P to D, until the chain is evenly stretched. Now measure the distances B C and B P, and find B E from the proportion

1 chain : B P : : B C : B E;

and the distance B E, measured from B to E, will give the foot of the perpendicular.

Reason.—If the point F be taken on the line B P at the distance of one chain from B, the distances D B, D C, and D F, are equal to each other, and C F is perpendicular to A B. Again, the sides about the common angle B of the triangles F B C and P B E being proportional, the triangles are equiangular (Eu. vi. 6); the angle B E P is equal to the right angle B C F, and P E is perpendicular to the given line A B.

252. PROBLEM 131.—*From a given point upon a given line on the ground, to lay off an angle equal to a given angle already laid down on the ground.*

METHOD I.—Measure any convenient distance, A F, Fig. 202, as one chain, from the angular point A, along one of the sides A B of the given angle; at F, set off a perpendicular F G, to intersect the other side of the angle in the point G, and measure F G and G A. Now, from the given point D, measure along the given line a distance, D E, equal to A F; from E set off a perpendicular, E H, to the line D E, and make E H equal to F G; then, if the work has been accurately performed, the distance D H will be equal to the distance A G, and the angle E D H will be equal to the given angle B A C.

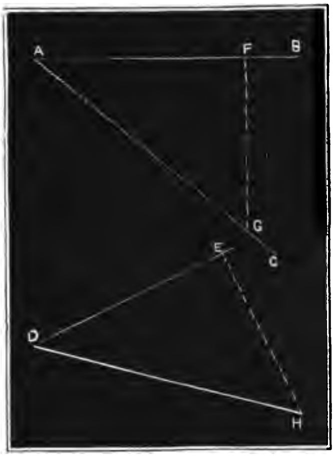

Fig. 202.

METHOD II.—Fix the first link of the chain at the point A, Fig. 203, and the last link at any convenient point F, upon A B, one of the sides of the given angle B A C, so that the chain may be sufficiently slack;* proceed along the line A C, carrying forward the chain, until, on arriving at the point G, the chain is evenly stretched in the position A G F, and mark the link at G. Now take up the chain, and having measured upon the given line the distance D E, from the given point D, equal to the distance A F, fix again the first link of the chain at the point D, and the last at the point E; take the marked link and retreat with it from the line, until at the point H the chain is again evenly stretched; and the angle E D H will be equal to the given angle B A C.

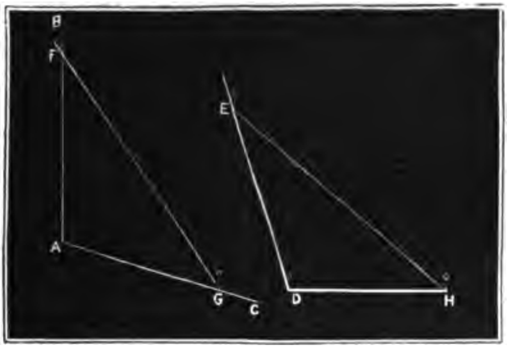

Fig. 203.

Reason.—In both methods, the triangles A F G and D E H are made equal in all respects.

253. PROBLEM 132.—*From a given point upon a given line on the ground, to lay off an angle of which the measurement is given in degrees and minutes.*

CASE I.—If the angle do not exceed 45°, measure a chain's length from the given point A, Fig. 204, along the given line A B to B, and at B set off a perpendicular, B C; take the tabular value of the trigonometrical tangent of the given angle from a table of natural tangents, and reckoning the two first digits on the left hand as a number of links, and the other digits as a decimal of a link, set off this distance on the line B C from B to C; then the angle B A C will be the angle required.

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* For angles between 40° and 90°, a half-chain will be found a very good distance; for angles less than 40°, a greater distance should be taken; and for angles greater than 90° a less distance should be taken.

Case II.—If the given angle be greater than 45°, lay off first from the given point A (Fig. 205), a line A D, at right angles to the given line, and then set off the angle D A C, equal to the complement of the given angle.

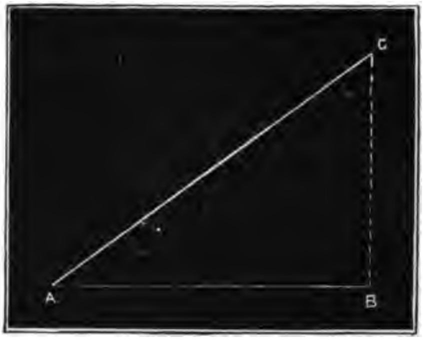

Fig. 204.

Check.—The tabular number representing the natural secant of the angle B A C or D A C, multiplied by 100, will give the number of links in the distance A C.

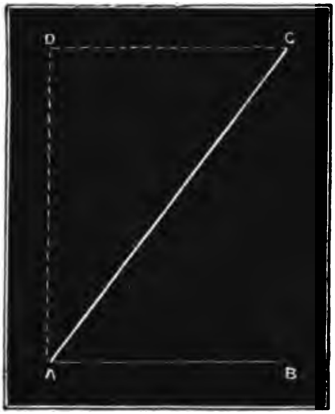

Fig. 205.

Example.—*To set off an angle of* 36° 30′.

The natural tangent of 36° 30″ is found from the tables to be ·73996, and multiplying this by 100, or taking the two figures on the left hand as integers, gives 73·996, or as nearly as can be measured, 74, for the number of links in the perpendicular B C. Again, the natural secant of 36° 30′ is found from the tables to be 1·2440, and this multiplied by 100 gives 124·4, or 124¼ very nearly, for the number of links in A C.

It is evident that this process may be inverted to measure an angle already laid down on the ground. Thus, having measured a chain's length or 100 links, from the angular point A, Fig. 204, along one side, A B, of the given angle, set off a perpendicular to A B, to meet the other side of the angle at C, and measure B C and A C; then, finding in the tables of tangents and secants the numbers most nearly agreeing with the links in B C and A C respectively, the corresponding number of degrees will be the measure of the given angle.

A measuring tape may be used in lieu of the chain, A B being made 100 feet, and the distances B C and A C being measured in feet; and the problem will be solved with equal facility.

Making A B an exact chain's length of 100 links, or an exact distance of 100 feet, enables the operator at once to take the number of links in B C and A C from the tables of tangents and secants. A B may, however, be of any length; but then the corresponding values of B C and A C will be respectively the products of this length multiplied by the natural tangent and by the natural secant of the angle B A C.

254. **Problem** 133.—*From a given point on the ground to set out a line parallel to a given straight line.*

Method I.—Through the given point P, Fig. 206, and any convenient point A, on the given line, set out the line A P; from any point C, on A P, set out a second line C B, to another point B on the given line; measure the distances, C P, C A, and C B; find the length C D from the proportion

C A : C P : : C B : C D;

then will the line P D be the required parallel.

Reason.—The line P D is made to cut the sides of the triangle C A B proportionally, and therefore (Theor. 15) P D is parallel to A B.

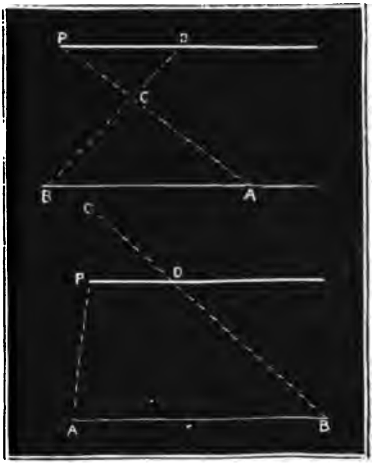

Fig. 206.

If the point C be taken at the middle of the line P A, then will C D be equal to C B.

Method II.—Set out a line from the given point P, Fig. 207, to any convenient point A on the given line A B; measure from A, a distance A C, on the line A P, and at C set off the perpendicular C D to meet the line A B at D. Again, from P

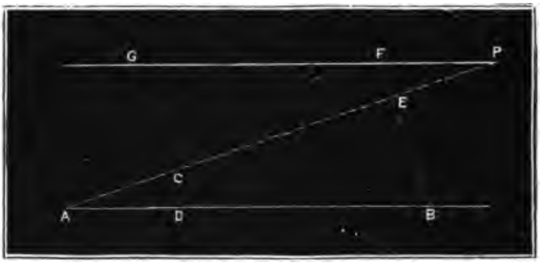

Fig. 207.

measure on the line P A the distance P E, equal to the distance A C, and at E set off the perpendicular E F, and make E F equal to C D; then the line P F will be parallel to the given line.

Reason.—The angle F P E is by this construction made equal to the alternate angle C A D, and, therefore (Theor. 8) the lines A B and P F are parallel.

Check.—Measure the length of C G, the production of D C to the line P F, then the following proportion should hold good:

P E : E F : : P C : C G.

Again, produce F E to meet the given line A B at B; then, should E B be equal to C G.

255. **Problem** 134.—*To set out a line on the ground that shall pass through a given inaccessible point, and be parallel to a given straight line.*

Set up a rod at any convenient point, D, Fig. 208, and another at E, in the same line with P and D; and also set up a rod at a point A upon the given line, and another at C in the same line with A and P. Through A, set out A F, parallel to D E (Prob. 133), and through any point F, in this line, set out B E, parallel to A C, intersecting A B and D E in the points B and E. Now measure F B, and set off from E, upon the line E B, the distance E G equal to F B. Then G will be a point on the parallel to A B, passing through P, which can therefore be set out by fixing rods in the same line with P and G.

Reason.—By the construction, P F is a parallelogram, and therefore (Theor. 11) the opposite sides P E and A F are equal; also E G is by construction made equal to F B; and A F and D E being parallel, the exterior angle A F B is (Theor. 9) equal to the interior and opposite angle P E G; therefore (Theor. 1), the triangles P E G and A F B are equal in all respects. Hence the angle E G P being equal to the interior and opposite angle F B A, P G is (Theor. 9) parallel to A B.

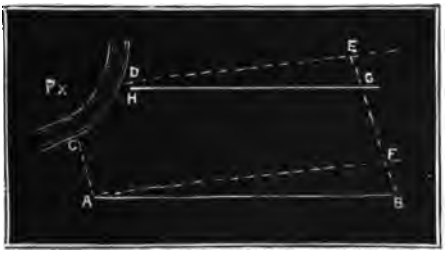

Fig. 208.

256. Problem 135.—*To set out on the ground a line parallel to a given straight line, and at a given distance from it.*

From any convenient point A, Fig. 209, on the given line A B, set off A C perpendicular to A B, and equal to the given distance. To check the work, fix a rod at *c*, the middle point of A C, and, A *a*, A *b*, and C *d*, being taken equal to each other, *a c*, *b c*, and *c d* will be equal to each other, and *b*, *c*, and *d* will be in the same straight line. Again, from a second convenient point B, on the line A B, set off the perpendicular B D equal to the given distance, and test it in the same manner by mark-

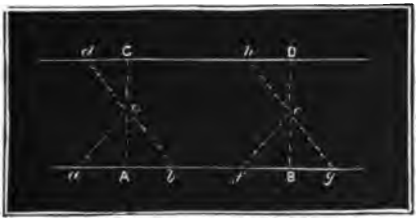

Fig. 209.

ing its middle point *e* and setting off B *f*, B *g*, and D *h*, all equal to each other. Then the line joining C and D shall be the parallel required.

257. **Problem** 136.—*To measure a line which passes through some obstruction, as a sheet of water, a clump of trees, or a building, the two ends of the line being accessible.*

Method I.—Measure a distance from one end A, Fig. 210, of the line, to a point C, from which a straight line can be run to the other end B of the line; leave a mark at B, and measure on the production of A C the distance C E, equal to A C. Now measure from B to C, and continue on in the same straight line to D, until C D is equal to C B. Lastly, measure D E, which will be equal to the required distance.

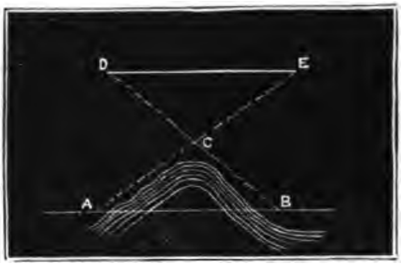

Fig. 210.

Reason.—The triangles A C B and D C E are by the construction made equal in all respects.

Method II.—When there is an obstruction which renders it impracticable to make C E and C D, Fig. 211, equal to C A and C B.

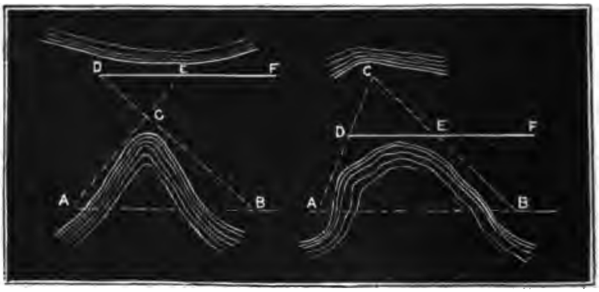

Fig. 211.

Case 1.—Continue A C to E; measure A C, C E, and C B· compute C D from the proportion

A C : C E : : B C : C D.

Continue B C to D, making C D equal to the computed distance. Again, compute D F from the proportion

D C : C B : : D E : D F;

and D F will be equal to A B.

Case 2.—Measure a convenient distance C D, back from C towards A; compute C E from the proportion

C A : C D : : C B : C E;

set off the computed distance C E from C upon C B. Then compute D F from the proportion

C D : C A : : D E : D F;

and D F will be equal to A B.

Neither the line D F nor any portion of it should be set out on the ground; but it is introduced in the figure to represent the result to the eye.

Method III.—Continue C B, Fig. 212, on to D, making B D equal to B C; at D make the angle B D E equal to the angle A C B (Prob. 131), and set off D E equal to A C; then will B E be equal to the required distance, A B.

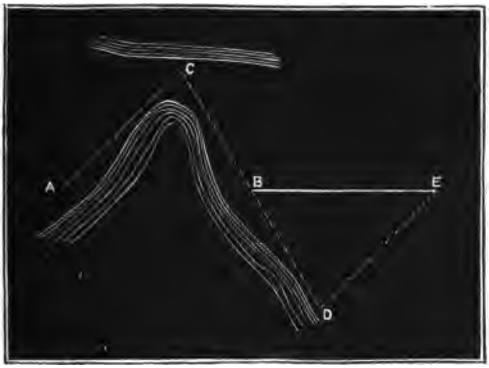

Fig. 212.

Reason.—B D, D E, being made equal to B C, C A, and the angle B D E to the angle A C B, the triangle B D E is equal

(Theor. 1) to the triangle A C B in all respects, and the base B E is equal to the base A B.

258. Problem 137.—*To measure a distance from one point, which is accessible, to another point, which can be seen, but is inaccessible.*

Method I.—A, Fig. 213, being the accessible point, and B the inaccessible, mark any convenient point C, in the same straight line with A and B, and, setting out the lines C D and A F, intersecting in E, make the distance E D equal to E C, and E F equal to A E. Then, setting out the line D F G through the points D and F, find upon this line the point G in the same straight line with E and B, and, measuring the distance F G, this will be equal to the distance A B.

Reason.—By the construction, D G is made parallel to A C (Prob. 133). Hence the angles E F G and E G F are (Theor. 8) respectively equal to the angles E A B and E B A; and the side E F has been made equal to the side E A; therefore (Theor. 3), the triangles E F G and E A B are equal in all respects; and F G is equal to A B.

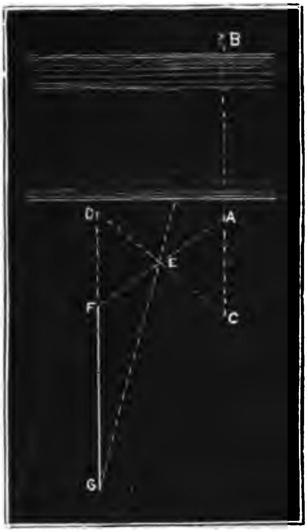

Fig. 213.

Method II.—Mark a point C, Fig. 214, in the same line with A and B, as before, and setting out the lines C F and A F, intersecting in F, mark upon these lines the points E and G, so that

$$C F : F E :: A F : F G.$$

Then setting out the line E G D, through the points E and G, find upon this line the point D in the same straight line with F and B; and measuring the distance G D, the required distance, A B, will be given by the proportion

$$F G : F A :: G D : A B.$$

Reason.—The line E D is, by the construction, made parallel to C B (Theor. 15). Hence (Theor. 9), the angles F G D and F D G are equal to the interior and opposite angles F A B and F B A; the triangles F G D and F A B, are therefore equiangular, and (Theor. 18) have their sides about the equal angles proportional.

Note.—If the point A be inaccessible as well as B, still, if the line A B can be sighted, and its production marked out, these methods will determine the distance of each of them from any assumed point upon the line thus produced, and, therefore, also the distance from A to B.

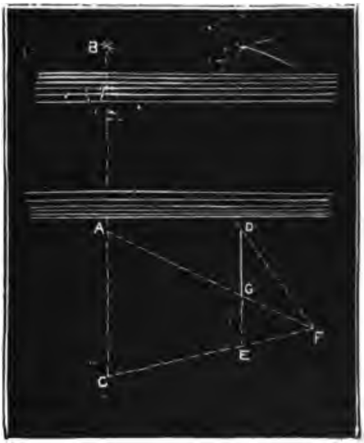

Fig. 214.

259. Problem 138.—*To measure the distance between two points* A *and* B, *when no part of the line* A B *is accessible, so that the line* A B *cannot be sighted.*

Set out a line, C D, Fig. 215, to pass through the point A, and a line E F (Prob. 134) parallel to C D, to pass through the point B. Set out a line from any convenient point C, on A C D, to a point E, upon the line B E F, and set up a rod at its middle point G. Find the point D upon A C D in the same straight line with G and B, and the point F upon B E F in the same straight line with A and G. Now measure the distance from D to F, and this shall be equal to the required distance from A to B.

Reason.—A D being parallel to B F, the angles G C D and G D C are (Theor. 8) respectively equal to the angles G E B and G B E; and by construction. G C is equal to G E; and,

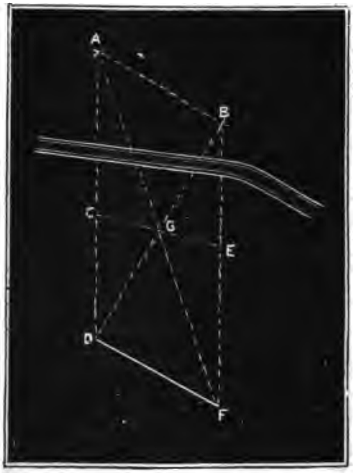

Fig. 215.

therefore (Theor. 3), C D is equal to B E. In like manner, E F is equal to A C. Hence, A D is equal to B F; and, since it is also parallel to it, D F is (Theor. 10) equal and parallel to A B.

Note.—The distances A C and A G, being equal to the distances F E and F G, are to be measured; and thus the exact position of A will be determined; and the exact position of B can be determined in like manner.

APPENDIX.

	Tangents.	Secants.	Tangents.	Secants.	Tangents.	Secants.	
	0°		1°		2°		
0′	0000	1·0000	0175	1·0002	0349	1·0006	0′
10	0029	1·0000	0204	1·0002	0378	1·0007	10
20	0058	1·0000	0233	1·0003	0407	1·0008	20
30	0087	1·0000	0262	1·0003	0437	1·0010	30
40	0116	1·0001	0291	1·0004	0466	1·0011	40
50	0145	1·0001	0320	1·0005	0495	1·0012	50
	3°		4°		5°		
0′	0524	1·0014	0699	1·0024	0875	1·0038	0′
10	0553	1·0015	0729	1·0027	0904	1·0041	10
20	0582	1·0017	0758	1·0029	0934	1·0043	20
30	0612	1·0019	0787	1·0031	0963	1·0046	30
40	0641	1·0021	0816	1·0033	0992	1·0049	40
50	0670	1·0022	0846	1·0036	1022	1·0052	50
	6°		7°		8°		
0′	1051	1·0055	1228	1·0075	1405	1·0098	0′
10	1080	1·0058	1257	1·0079	1435	1·0102	10
20	1110	1·0061	1287	1·0082	1465	1·0107	20
30	1139	1·0065	1317	1·0086	1495	1·0111	30
40	1169	1·0068	1346	1·0090	1524	1·0115	40
50	1198	1·0072	1376	1·0094	1554	1·0120	50
	9°		10°		11°		
0′	1584	1·0125	1763	1·0154	1944	1·0187	0′
10	1614	1·0129	1793	1·0160	1974	1·0193	10
20	1644	1·0134	1823	1·0165	2004	1·0199	20
30	1673	1·0139	1853	1·0170	2035	1·0205	30
40	1703	1·0144	1883	1·0176	2065	1·0211	40
50	1733	1·0149	1914	1·0181	2095	1·0217	50
	12°		13°		14°		
0′	2126	1·0223	2309	1·0263	2493	1·0306	0′
10	2156	1·0230	2339	1·0270	2524	1·0314	10
20	2186	1·0236	2370	1·0277	2555	1·0321	20
30	2217	1·0243	2401	1·0284	2586	1·0329	30
40	2247	1·0249	2432	1·0291	2617	1·0337	40
50	2278	1·0256	2462	1·0299	2648	1·0345	50
	Tangents.	Secants.	Tangents.	Secants.	Tangents.	Secants.	

	Tangents.	Secants.	Tangents.	Secants.	Tangents.	Secants.	
	15°		16°		17°		
0′	2679	1·0353	2867	1·0403	3057	1·0457	0′
10	2711	1·0361	2899	1·0412	3089	1·0466	10
20	2742	1·0369	2931	1·0421	3121	1·0476	20
30	2773	1·0377	2962	1·0429	3153	1·0485	30
40	2805	1·0386	2994	1·0439	3185	1·0495	40
50	2836	1·0394	3026	1·0448	3217	1·0505	50
	18°		19°		20°		
0′	3249	1·0515	3443	1·0576	3640	1·0642	0′
10	3281	1·0525	3476	1·0587	3673	1·0653	10
20	3314	1·0535	3508	1·0598	3706	1·0665	20
30	3346	1·0545	3541	1·0608	3739	1·0676	30
40	3378	1·0555	3574	1·0619	3772	1·0688	40
50	3411	1·0566	3607	1·0631	3805	1·0699	50
	21°		22°		23°		
0′	3839	1·0711	4040	1·0785	4245	1·0864	0′
10	3872	1·0723	4074	1·0798	4279	1·0877	10
20	3906	1·0736	4108	1·0811	4314	1·0891	20
30	3939	1·0748	4142	1·0824	4348	1·0904	30
40	3973	1·0760	4176	1·0837	4383	1·0918	40
50	4006	1·0773	4210	1·0850	4417	1·0932	50
	24°		25°		26°		
0′	4452	1·0946	4663	1·1034	4877	1·1126	0′
10	4487	1·0961	4699	1·1049	4913	1·1142	10
20	4522	1·0975	4734	1·1064	4950	1·1158	20
30	4557	1·0989	4770	1·1079	4986	1·1174	30
40	4592	1·1004	4806	1·1095	5022	1·1190	40
50	4628	1·1019	4841	1·1110	5059	1·1207	50
	27°		28°		29°		
0′	5095	1·1223	5317	1·1326	5543	1·1434	0′
10	5132	1·1240	5354	1·1343	5581	1·1452	10
20	5169	1·1257	5392	1·1361	5619	1·1471	20
30	5206	1·1274	5430	1·1379	5658	1·1490	30
40	5243	1·1291	5467	1·1397	5696	1·1509	40
50	5280	1·1208	5505	1·1415	5735	1·1528	50
	Tangents.	Secants.	Tangents.	Secants.	Tangents.	Secants.	

	Tan-gents.	Secants.	Tan-gents.	Secants.	Tan-gents.	Secants.	
	30°		31°		32°		
0'	5774	1·1547	6009	1·1666	6249	1·1792	0'
10	5812	1·1566	6048	1·1687	6289	1·1813	10
20	5851	1·1586	6088	1·1707	6330	1·1835	20
30	5890	1·1606	6128	1·1728	6371	1·1857	30
40	5930	1·1626	6168	1·1749	6412	1·1879	40
50	5969	1·1646	6208	1·1770	6453	1·1901	50
	33°		34°		35°		
0'	6494	1·1924	6745	1·2062	7002	1·2208	0'
10	6536	1·1946	6787	1·2086	7046	1·2233	10
20	6577	1·1969	6830	1·2110	7089	1·2258	20
30	6619	1·1992	6873	1·2134	7133	1·2283	30
40	6661	1·2015	6916	1·2158	7177	1·2309	40
50	6703	1·2039	6959	1·2183	7221	1·2335	50
	36°		37°		38°		
0'	7265	1·2361	7536	1·2521	7813	1·2690	0'
10	7310	1·2387	7581	1·2549	7860	1·2719	10
20	7355	1·2413	7627	1·2577	7907	1·2748	20
30	7400	1·2440	7673	1·2605	7954	1·2778	30
40	7445	1·2467	7720	1·2633	8002	1·2807	40
50	7490	1·2494	7766	1·2661	8050	1·2837	50
	39°		40°		41°		
0'	8098	1·2868	8391	1·3054	8693	1·3250	0'
10	8146	1·2898	8441	1·3086	8744	1·3284	10
20	8195	1·2929	8491	1·3118	8796	1·3318	20
30	8243	1·2960	8541	1·3151	8847	1·3352	30
40	8292	1·2991	8591	1·3184	8899	1·3386	40
50	8342	1·3022	8642	1·3217	8952	1·3421	50
	42°		43°		44°		
0'	9004	1·3456	9325	1·3673	9657	1·3902	0'
10	9057	1·3492	9380	1·3711	9713	1·3941	10
20	9110	1·3527	9435	1·3748	9770	1·3980	20
30	9163	1·3563	9490	1·3786	827	1·4020	30
40	9217	1·3600	9545	1·3824	9884	1·4061	40
50	9271	1·3636	9601	1·3863	9942	1·4101	50
60					1·0000	1·4142	60
	Tan-gents.	Secants.	Tan-gents.	Secants.	Tan-gents.	Secants.	

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